Buyer Aware? TOPCon's Reliability Issues in Comparison with PERC PV Modules After Damp Heat Testing

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Abstract

Currently, bifacial p-type passivated emitter and rear cells (PERC) have the largest share in the photovoltaic market. However, it is predicted that n-type tunnel oxide passivated contact (TOPCon) technology will soon gain a significant market share. Despite technological advancements, there are still concerns about the reliability of TOPCon when used in the field that need to be addressed. This work examines the humidity-induced degradation in bifacial n-type TOPCon and p-type PERC glass backsheet modules. Different bills of materials (BOM) are utilized in the study, encompassing polyolefin elastomer (POE), ethyl-vinyl acetate (EVA), and a range of backsheet options. We find that modules with PERC cells remain stable with only a 1-2%$_{rel}$ maximum power loss (P_{max}) after 1000 hrs of damp heat (DH) testing, regardless of the BOM used. However, after the same DH testing duration, modules with TOPCon cells experienced severe degradation with a drop in P_{max} ranging from 4-65%$_{rel}$. This can be attributed to a significant increase in series resistance (R_s). It is probable that the increase in R_s following DH testing is caused by an electrochemical reaction between moisture, soldering flux, and/or contaminants such as sodium chloride and the metallization of solar cells. This reaction results in contact corrosion and is particularly noticeable in TOPCon cells, causing R_s to increase by up to ~3 orders of magnitude after just 1000 hrs of DH testing. Despite using POE, an expensive encapsulant type, no advantages were found compared to the cheaper material, EVA. The observed outcome emphasizes the susceptibility and potential failure of the metalization in TOPCon solar cells when exposed to high humidity and contaminants in the field. Consequently, more research is required to gain a better understanding and enhance the reliability of TOPCon cells against the harmful impact of moisture and other contaminants.

1. Introduction

It is essential for photovoltaic (PV) systems to maintain long-term stability to reduce the cost of electricity generation. A PV system should ideally perform at a high level for 25 to 50 years, with a maximum reduction of 20% in relative performance, making long-term stability even more crucial [1]. Bifacial passivated emitter and rear cell (PERC) and tunnel oxide passivated contact (TOPCon) solar cells are the mainstream silicon cell technologies that currently (or are projected to) dominate the solar market share due to their high efficiency and manufacturability [2]. Despite being advanced, TOPCon solar cells still face reliability issues that cause substantial power loss when subjected to high humidity [3]. This is particularly true when they are encapsulated using low-cost materials like ethyl-vinyl acetate (EVA) [3]. To prevent these issues, bifacial TOPCon cells often employ polyolefin elastomer (POE) for encapsulation, along with glass sheets on both the front and back sides and edge sealant in some cases [4]. However, these modules present a greater risk of damage, added weight, and elevated manufacturing expenses [5,6]. A glass-backsheet module with EVA encapsulation would be the ideal choice due to its affordability, provided that it can successfully prevent any failures caused by humidity or other contaminants. To address the problem of humidity-induced degradation in TOPCon cell technologies, it is crucial to conduct thorough research. Therefore, in this study, we aim to examine the effects of the bill of materials (BOM) on the reliability of PERC and TOPCon solar cells.

2. Experiment

Bifacial n-type silicon PERC and TOPCon solar cells sourced from industry were used in this work. The PERC cells featured a phosphorous-doped emitter (n^+ emitter), hydrogenated silicon nitride (SiN_x:H) passivation layer, and screen-printed H-pattern silver grid on the front side. At the rear side, there was an aluminium oxide (Al_2O_3)/SiN_x:H passivation layer stack and a screen-printed H-pattern aluminium 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/phosphorus-doped poly silicon (n^+poly-Si)/SiN_x:H stack and a screen-printed H-pattern silver grid. All cells were then soldered on both sides to connect ribbon/tabbing wires to the busbar of cells, creating an 8-cell series. Subsequently, PERC cells were encapsulated with various BOM to create module structures, as listed below:

1. A front glass sheet, EVA on both sides and backsheet type F at the rear side, herein referred to as "(1) p-G/EVA/BS-F"
2. A front glass sheet, POE on both sides and backsheet type WT on the rear side, herein referred to as "(2) p-G/POE/BS-WT"
3. A front glass sheet, POE on both sides and backsheet type W on the rear side, herein referred to as "(3) p-G/POE/BS-W"
4. A front glass sheet, POE type A on both sides, and backsheet type WT on the rear side, herein referred to as "(4) p-G/POE-A/BS-WT"

Similarly, n-type TOPCon cells were also encapsulated with different BOM to form modules structures as follows:

1. A front glass sheet, POE on both sides and backsheet type W at the rear side, herein referred to as "(1) n-G/POE/BS-W"
2. A front glass sheet, POE type A on both sides and backsheet type WT at the rear side, herein referred to as "(2) n-G/POE-A/BS-WT"
3. A front glass sheet, POE type A on both sides and backsheet type W at the rear side, herein referred to as "(3) n-G/POE-A/BS-W"
4. A front glass sheet, POE type A on both sides, and a black backsheet at the rear side, herein referred to as "(4) n-G/POE-A/BS-B"
5. A front glass sheet, POE type B on both sides and backsheet type W at the rear side, herein referred to as "(5) n-G/POE-B/BS-W"
6. A front glass sheet, POE type B on both sides and backsheet type WT at the rear side, herein referred to as "(6) n-G/POE-B/BS-WT"
7. A front glass sheet, EVA on both sides and backsheet type W at the rear side, herein referred to as "(7) n-G/EVA/BS-W"

The processes involved in encapsulating the modules were carried out at an industrial facility. These processes included soldering to connect ribbon and tabbing wires to the busbars and laminating to join BOM forming modules. All modules underwent a damp heat (DH) test at 85 °C and 85% relative humidity (RH) for up to 1000 hrs to study humidity-induced failures. Fig 1 provides a detailed experimental flow diagram in this work. The current-voltage (I-V) measurements were performed at standard testing conditions at the initial state and after incremental steps during the DH test using a commercial module flash tester (Eternalsun Spire, Spi-Sun Simulator™ 5600SLP Blue System) tool. Line scan electroluminescence (EL) and photoluminescence (PL) images were captured for all samples using a BTi-M1 luminescence line-scan system before and after 1000 hrs of DH testing.

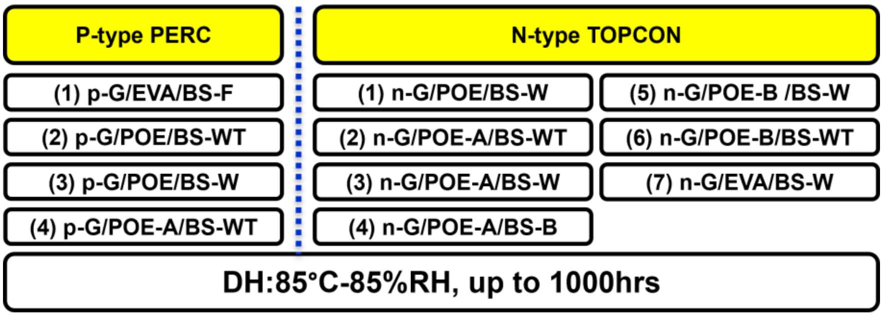


Figure 1. Experimental flow diagram.

3. Results and discussion

Fig 2 shows the changes in maximum power (P_{max}) and series resistance (R_s) after DH testing of all modules. After 1000 hrs of the DH test, it was found that the P_{max} of modules with PERC cells degraded only by 1-2%$_{rel}$. The leading cause of this degradation was an increase in R_s, which had risen by ~10%$_{rel}$. There was no considerable disparity in the degree of P_{max} loss observed when employing EVA, POE, or either backsheet W or WT. This outcome highlights the inherent stability of the PERC cell, demonstrating that both high-quality (POE) and lower-quality (EVA) encapsulation methods have negligible effects on the reliability of the PERC cells. However, it was observed that modules with TOPCon cells experienced a significant decrease in P_{max}, ranging from 4%$_{rel}$ to 65%$_{rel}$. This loss was attributed to a considerable increase in R_s, which rose ~1 to ~3 orders of magnitude. No clear trend was observed when altering the BOM by using EVA, POE, or a different backsheet. Note that no significant changes in open circuit (V_{OC}) and short current (J_{SC}) were observed in the modules with both PERC and TOPCon cells (data not shown).

Fig 3 illustrates the evolution of EL images before and after 1000 hrs of DH testing of modules with both PERC and TOPCon cells. The EL intensity for modules containing PERC cells remained largely unchanged before and after 1000 hrs of DH testing, as shown in Fig 3(a). The observed alterations were minimal in nature. These results were consistent with the data obtained through the I-V tester, revealing no significant alteration in both P_{max} and R_s for the modules within the PERC group. However, after 1000 hrs of DH testing, a noticeable reduction in EL intensity was observed in modules with TOPCon cells, with the most significant impact seen in modules in the groups (5) n-G/POE-B/BS-W and (6) n-G/POE-B/BS-WT, as depicted in Fig 3(b). No clear failure pattern was observed when altering the BOM (EVA, POE, or backsheet). In nearly every module featuring TOPCon cells, certain failures were already evident (indicated by low-intensity EL counts) prior to the DH test. These failures manifested as dark dots and/or dark rectangular patterns randomly situated within the modules, as depicted in Fig 3(b). After 1000 hrs of DH testing, the majority of the failures had worsened, particularly in Group (1) n-G/POE/BS-W, where the most noticeable issues were observed. These results imply that certain failures were likely present in some modules even before the start of the DH test, highlighting the heightened sensitivity of TOPCon cells in comparison to PERC cells. It should be noted that for all modules in this study, the intensity of PL increased after DH testing (data not shown due to space limitations). This suggests that the decrease in EL intensity across all modules in this study was primarily caused by an increase in R_s [7]. The changes in EL images corresponded with the changes in P_{max} and R_s, as measured by the I-V tester, where it was observed that there was a significant decrease in P_{max} and a substantial increase in R_s in modules with TOPCon cells, especially for the modules (5) n-G/POE-B/BS-W and (6) n-G/POE-B/BS-WT.

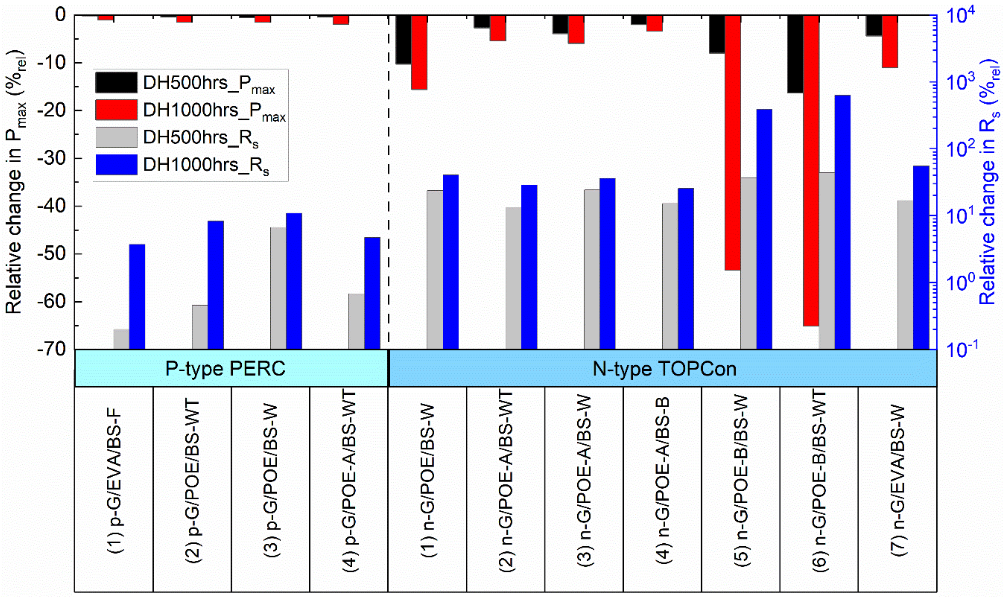
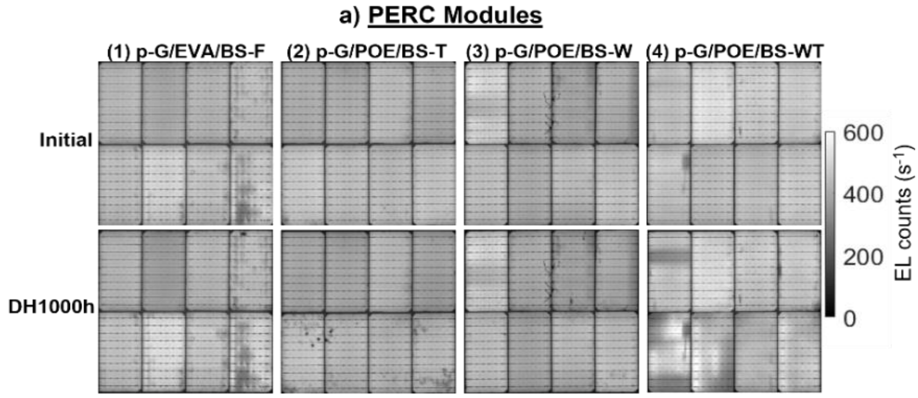


Figure 2: Relative changes in P_{max} and R_s after damp heat testing.

It is currently unclear what is causing a greater increase in R_s in modules with TOPCon compared to those with PERC cells. A study is underway to determine the exact cause. However, it is probable that the issue was caused by the soldering flux utilized to connect the ribbon wires and busbars of the cells or by some contamination that may have been inadvertently introduced to the cells before encapsulation. Studies have shown that some types of soldering flux can cause significant corrosion to the metal contact of solar cells [8,9]. This can lead to a substantial increase in R_s when exposed to high humidity and temperature levels. When soldering solar cells, the leftover flux (which contains weak acids, lead, tin or halide materials) can react with moisture and the metallization of the cells. This can cause contact corrosion, resulting in an increase in R_s after DH testing. The soldering flux used in this PV manufacturer is more likely to be sensitive to the metallization of TOPCon cells compared to PERC cells. As a result, more severe metal contact failure was observed in TOPCon cells after DH testing. These findings emphasize that choosing the suitable soldering flux for each cell technology is crucial. Furthermore, the significant degradation identified in the module with TOPCon cells is also likely related to contaminants like sodium chloride (NaCl). It has been established that human fingerprints often contain a significant amount of sodium (Na) and chlorine (Cl), which can lead to solar cell contamination during production if not handled properly [10,11]. Research conducted by UNSW has shown that NaCl has a severe impact on all types of cell technology. The study found that TOPCon cells were the most severely affected, while PERC cells showed less impact [12]. It was discovered that NaCl can cause rapid corrosion of the front contact of TOPCon cells. This can result in a P_{max} loss of up to 70%$_{rel}$ to just 20 hrs of DH testing in non-encapsulated cells. It is possible that the modules in this study could have been contaminated with NaCl. This contamination may have occurred during handling/storing, such as using gloves that were contaminated or direct contact with bare hands or placing cells in the containment area prior to encapsulation. However, owing to the higher sensitivity of the metallization in TOPCon cells towards NaCl compared to PERC cells, as demonstrated by researchers at UNSW, there was a more significant failure in modules containing TOPCon cells as opposed to PERC cells [12]. While acetic acid, a byproduct of EVA, has been considered a potential factor contributing to metallization corrosion in solar cells, resulting in elevated R_s after DH testing, it is improbable that this alone is responsible for the failures noted in this study [13]. This is evident as similar or even more pronounced failures were observed in modules encapsulated with POE, a material devoid of acetic acid.

These findings hold great importance for PV manufacturers, as they demonstrate that the metal contact of TOPCon cells is more sensitive to moisture, soldering flux, and external contaminants compared to PERC cells. Consequently, meticulous care must be exercised in the handling and choice of soldering flux for TOPCon cells in the manufacturing process. By taking these precautions, the risk of metal contact failure is potentially reduced, allowing for the use of cost-effective encapsulation like EVA.



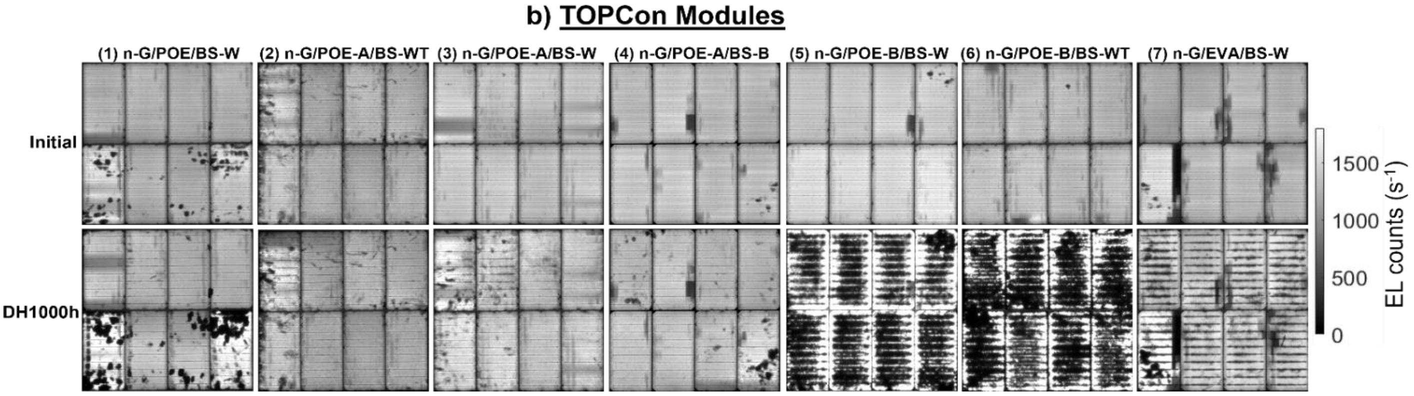


Figure 3 Electroluminescence images of modules with (a) PERC cells and (b) TOPCon cells before and after 1000hrs of DH testing.

4. Conclusion

To sum up, this study investigates the impact of humidity on bifacial n-type TOPCon and p-type PERC glass backsheet modules. Various BOM are employed, including POE, EVA, and different backsheet options. Our findings reveal that modules with PERC cells exhibit stability, with only a 1-2%$_{rel}$ P_{max} decrease after 1000 hrs of DH testing, regardless of the BOM utilized. Conversely, TOPCon cell modules experience severe degradation, with P_{max} decreasing by 4-65%$_{rel}$ after the same DH testing duration. This decline can be attributed to a notable increase in R_s. The increase in R_s after DH testing is likely due to an electrochemical reaction between moisture, soldering flux, and/or contaminants (such as sodium chloride) and the metallization of solar cells. This reaction leads to contact corrosion, which is particularly evident in TOPCon cells, causing R_s to increase by up to ~3 orders of magnitude after just 1000 hrs of DH testing. Despite using POE, an expensive encapsulant type, no advantages were observed compared to the cheaper material, EVA. The outcome highlights the vulnerability and potential failure of TOPCon solar cell metalization when exposed to high humidity and contaminants in the field. Therefore, more research is needed to improve the reliability of TOPCon cells against moisture and contaminants.

Acknowledgements

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