The Impact of Cold Temperature Exposure in Mechanical Durability Testing of PV Modules

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***Abstract* — Existing mechanical durability testing sequences typically perform mechanical loading prior to environmental exposures such as thermal cycling or humidity freeze. Recent work has shown that the fracture strength of silicon solar cells can reduce after exposure to temperatures below -20°C. In an effort to better evaluate modules with respect to cell crack durability, we explore the use of a single thermal cycle prior to mechanical loading. Modules were exposed to a static front-side load before and after exposure to a single thermal cycle and were characterized with current-voltage measurements and electroluminescence imaging. The results show a significant increase in the number of cell cracks that are generated at a given load after a single cold exposure. We explore how this can be used to further optimize the qualification test sequence for mechanical durability.**

***Index Terms* — cell fracture, mechanical durability, photovoltaic modules, reliability, silicon.**

I. Introduction

Mechanical durability is one of the most critical aspects of module reliability as modules commonly experience external mechanical loads from snow and wind once in the field [1]. To evaluate mechanical durability, a dynamic mechanical load test is typically performed which includes 1000 load cycles at ±1000 Pa, 50 thermal cycles (85°C to -40°C), and 10 humidity freeze cycles [2,3]. In this testing sequence, the cyclic loading is considered as the mechanical force that initiates cell cracking. The cyclic application of this load then start the process of opening these cell cracks [4]. Subsequent environmental tests (TC/HF) are used to apply thermo-mechanical loads that are meant to open cracks and stress cell metallization and interconnects. Even with this qualification test, mechanical durability and cell cracking remains a large concern for end users.

Recent work has demonstrated that once tabbed silicon solar cells are exposed to temperatures below -20°C their fracture strength is reduced [5]. These results indicate that environmental exposure is also important to consider during the crack creation phase of the mechanical durability sequence.

In this work we explore how a single thermal cycle impacts crack creation in two module types. Modules were exposed to a static front-side load before and after an exposure to a single thermal cycle and were characterized at each step with current-voltage measurements and electroluminescence imaging. The exact sequence followed is shown in Fig.1. The mechanical loading was carried out using a *LoadSpot* mechanical testing system.

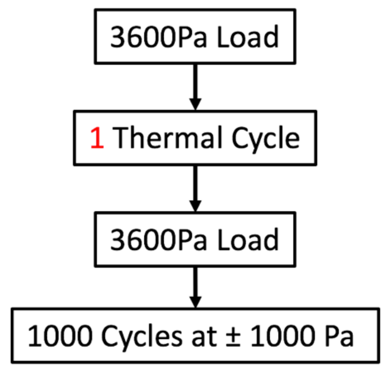

Fig. 1. Testing sequence used in this work to evaluate the impact of a single thermal cycle on crack durability.

II. Results and Discussion

Two module types were subjected to the testing sequence described in Fig.1. Module type 1 was a 60 cell mono-crystalline design while type 2 was a 72 cell multi-crystalline design and both modules types had four busbar interconnects.

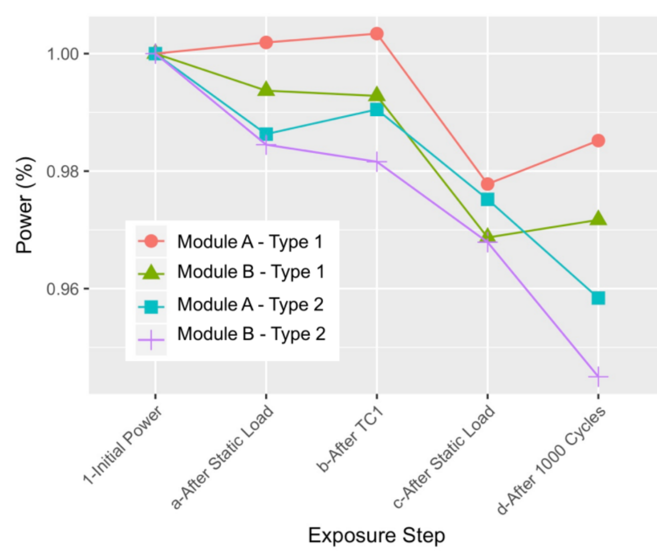

Fig. 2. Power degradation of four modules during each step of the durability testing sequence described in Fig. 1.

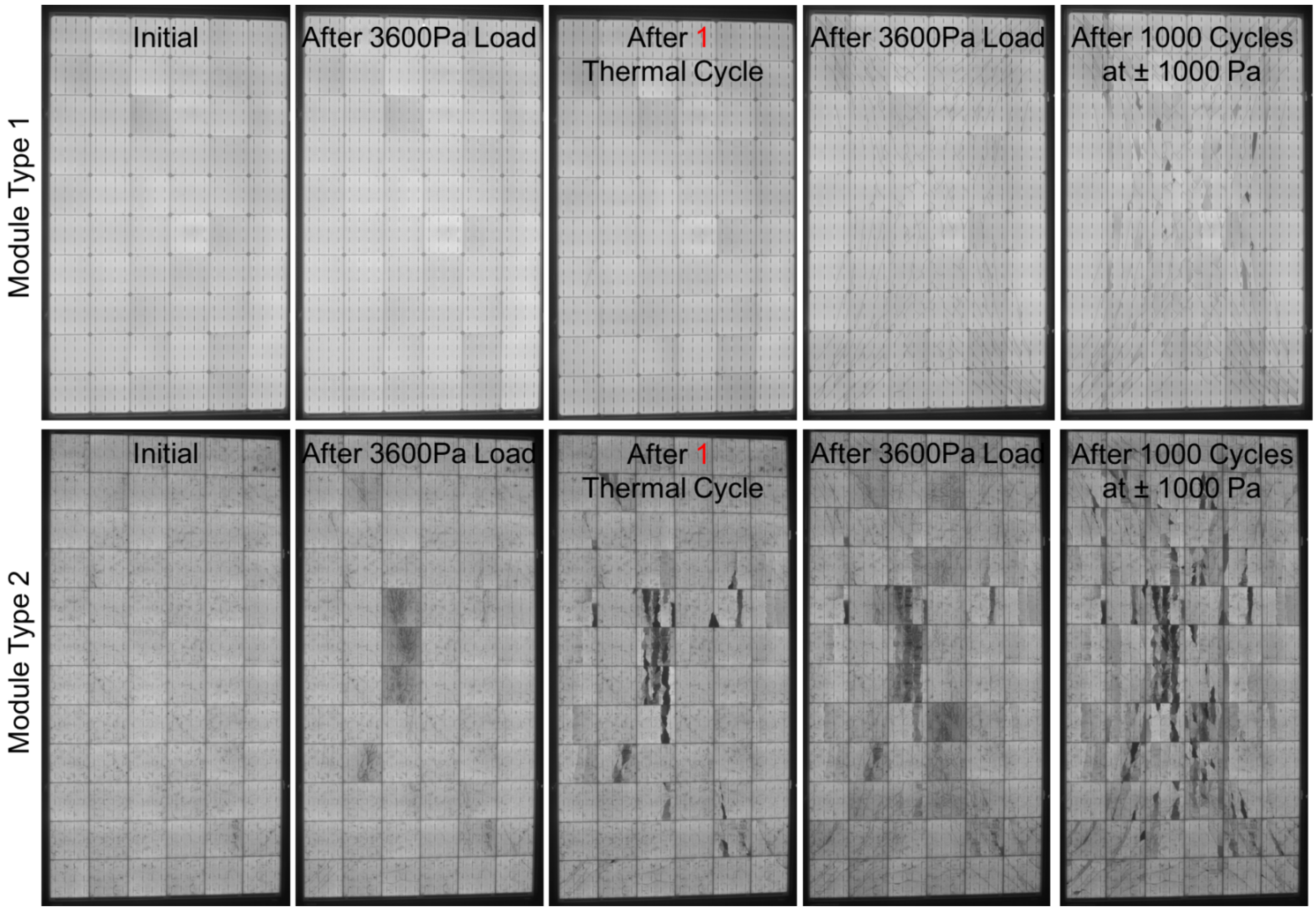

Fig. 3. EL images of a representative module for each of the two groups studied in this work. The impact of the single thermal cycle can be seen in the fourth image of the sequence where there is a substantial increase in the number of cell cracks.

A. Performance Degradation

Performance was measured after each step in the testing sequence. The relative performance of the modules after each exposure step is shown in Fig. 2. An example of the EL images for one module from each group is shown in Fig. 3. After the initial 3600 Pa load, there was only a small change (less than 2%) in the power for both module types. This was due to the relatively low number of cracks generated during this step (less than 10 cracked cells), with the exception of Module B from Type 2 (just over 20 cracked cells). The number of crack cells is shown in Fig. 4 for each of the exposure steps.

There was very little change in either the power or the number of cracked cells after the single thermal cycle (TC1). For module type 2, TC1 did appear to open some of the existing cracks. This crack opening, however, did not appear to have a significant impact on power.

Following TC1 the modules were then re-exposed to the same 3600 Pa load that was previously applied to the modules. This resulted in a drastic increase in the number of cracked cells. The number of cracked cells accounted for over 90% of the total number of cells in each module. This remarkable increase in the number of cell cracks resulted in only a minor decrease in overall module performance.

The final step of the testing sequence was a standard cyclic loading sequence of 1000 cycles of ±1000 Pa load. The purpose of this test was to open the newly created cracks. As shown in the final image for both modules in Fig. 3, there is an increase in the number of open cracks (*i.e.* dark regions) after this cyclic loading step. Module Type 1 appears more durable with respect to crack opening, as there was no significant change in the output power. Module Type 2, however, reduces even further in power with one module falling below the typical 5% power loss criteria.

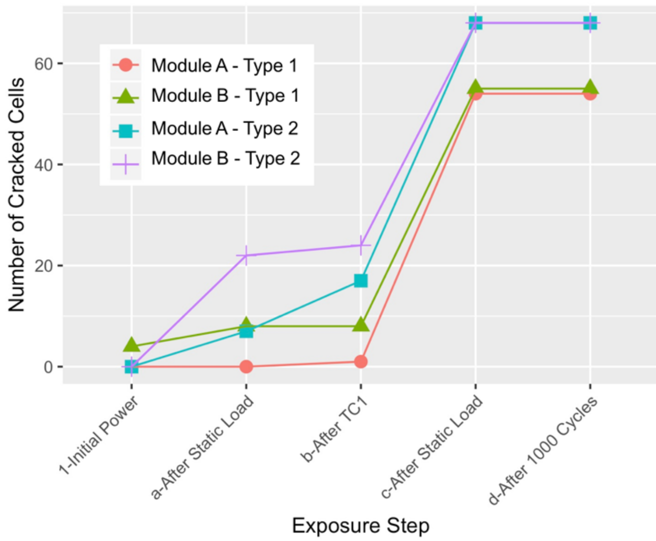

Fig. 4. EL Count of cracked cells after each step of the durability testing sequence described in Fig. 1.

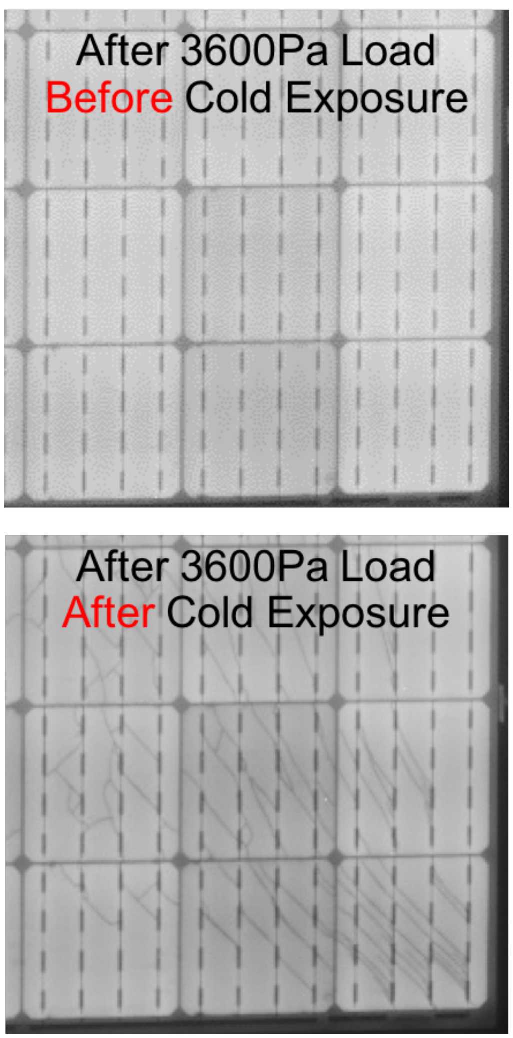

Fig. 5. Magnified image of the cracks created after cold exposure for one module.

B. Crack Creation

These results highlight that the TC/HF exposure is not only useful as a crack opening test, but also as part of a crack creation sequence. The precise mechanism is explored in other ongoing work [6], but from the magnification of several cells in Fig. 5. it is clear that the cracks either start or end at a busbar. The interaction of the interconnect ribbon, encapsulant and backsheet at very low temperatures appears to apply a substantial stress to the cell resulting in microdefects that quickly propagate into full cell cracks after further mechanical load.

The number of cracked cells is considerably larger than what would be observed after the initial loading cycle, and certainly much larger than what would be expected after the first phase of the standard qualification testing sequence (1000 cycles of ±1000 Pa). It may be more appropriate in future qualification testing sequences to extend the test sequence so that there is at least one more cyclic loading sequence after TC50/HF10. This test would validate module designs that overcome this cold temperature effect for use in cold climates.

III. Conclusions

Modules in climates that experience large snow loads, will likely also be exposed to considerably cold temperatures at least once over the lifetime of a system. This one single exposure is all that is needed to reduce the fracture strength of the cells and result in substantial cell cracking during a subsequent mechanical loading event. In this work we show that just a single cold exposure, followed by a moderate front-side load of 3600 Pa results in over 90% of cells exhibiting at least one crack. This result identifies a potential oversight in the current qualification testing sequence that merits further discussion regarding how to adequately evaluate module designs with respect to this degradation mechanism.

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