Translating Materials-Level Characterization of Carbon-Nanotube-Reinforced Composite Gridlines To Module-Level Degradation

Andre Chavez[1,2], Brian Rummel[1,2], April Jeffries[2], and Sang M. Han[1,2]
Nick Bosco[3]
Brian Rounsaville[4] and Ajeet Rohatgi[4]

[1]University of New Mexico, Albuquerque, NM 87131
[2]Osazda Energy, Albuquerque, NM 87102
[3]National Renewable Energy Laboratory, Golden, CO 80401
[4]Georgia Institute of Technology, Atlanta, GA 3033

Abstract — Cell cracks in PV modules caused by environmental stressors and extreme weather events can lead to gradual or immediate power degradation. To directly address cell-crack-induced degradation, we have formulated a carbon nanotube additive for commercial silver pastes used in screen printing. We have shown in earlier work that these metal matrix composites do not impact the cell efficiency, while enhancing the metallization's fracture toughness and electrical gap-bridging capability. In this work, we focus on translating materials-level characterization techniques to module-level degradation. We found that we get conflicting results from two different materials characterization methods of measuring the metallization's ability to electrically bridge gaps in cracked solar cells. To determine which materials characterization method correlates better with the mini-module degradation characteristics, we have conducted stress testing for a small dataset of mini-modules.

The first characterization method for measuring the metallization's ability to electrically bridge cell cracks is dubbed as Resistance Across Cleaves and cracKs (RACK), in which a piezoelectric stage pulls apart fractured cells in submicron increments while the resistance of the gridlines on top of the fractured cells is measured until the gridlines electrically fail. The tensile stress applied to the metallization during the RACK test is intended to mimic the stress encountered by the metal gridlines during thermal cycling after cell fracture, in which cell fragments translocate within the module. Another common method for characterizing the metallization's ability to electrically bridge cell cracks is three-point bending test, where a rectangular substrate with two parallel gridlines, laser-diced from a cell, is mounted on an acrylic beam and placed in a three-point bend fixture while the resistance of gridlines is monitored as a crack in the cell is slowly opened. The failure mechanism with this testing method could be an alternative representation of how a cell would fracture when the module is being flexed under heavy mechanical loads or being stepped on.

The two materials-level characterization methods described above are designed to measure the metallization's ability to electrically bridge a cracked cell; however, they give conflicting results as to which composition and geometry of carbon nanotubes performs best. To better understand which materials-level test correlates to module-level degradation, 2×2 minimodules were constructed with pre-fractured cells and subjected to thermal cycling. The power loss for

composite-enhanced modules after thermal cycling, so far, is similar to the baseline-paste modules. To obtain statistically conclusive results, additional mini-module stress testing is currently underway to shed light on which CNT composition and geometry will provide maximum gap bridging capability and increase in module durability.

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