Impact of module construction in providing reliability redundancy through accelerated lifetime testing

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Introduction

Crystalline silicon modules manufactured using solder coated copper ribbon and fired glass frit metallization have shown excellent reliability. In this study, we show that the robustness of modules can be attributed to the redundant nature of the module construction whereby even poor mechanical interfaces can be reinforced in the module laminate and maintain high electrical performance.

Module construction and test conditions

Three different test vehicles were fabricated for interval measurements:

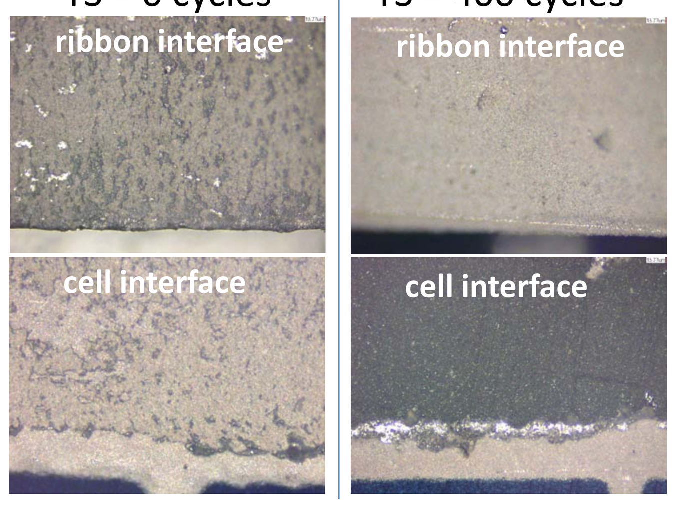
- Bare cells for peel testing
- Unencapsulated strings (2x1 cells)
- Laminated modules (2x1 cells)

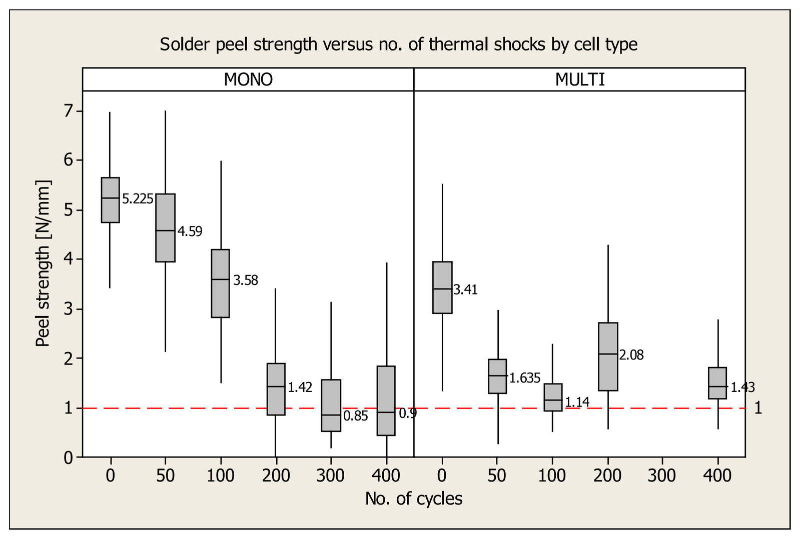
Each of the test vehicles were subjected to two different stress conditions. For accelerated damp heat testing, HAST testing at 120C/100%RH was performed whilst, for accelerated temperature cycling, samples were subjected to thermal shocks from 85C to -40C at a rate of 50 cycles per day. Module construction was made with representative industry standard materials (SnPb ribbon, EVA encapsulant, low iron glass and TPE backsheet) and commercially available multi-crystalline and mono-crystalline cells.

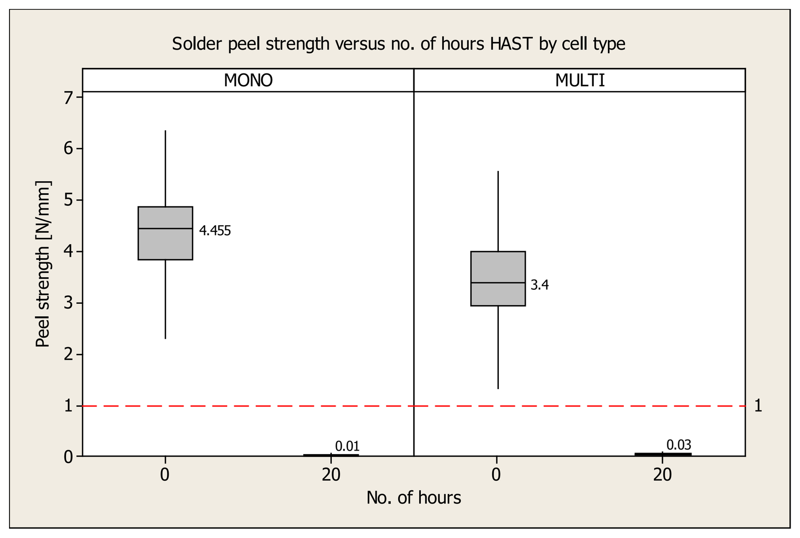
Peel strength measurements

Accelerated life testing is believed to reduce the peel strength of the ribbon/paste soldered interconnect due to a combination of thermo-mechanical stresses in the case of thermal shock and oxidation in the case of HAST. The peel strength drops from a median value of 4.5N/mm to approx. 1.5N/mm after 400 thermal shocks and less than 0.1N/mm after just 20hours of HAST. The optical microscope images below show the peel interface after beginning of life peel testing with cohesive failure in the paste/solder interface and after 400 thermal shocks with failure at the paste/silicon interface.

TS = 0 cycles TS = 400 cycles







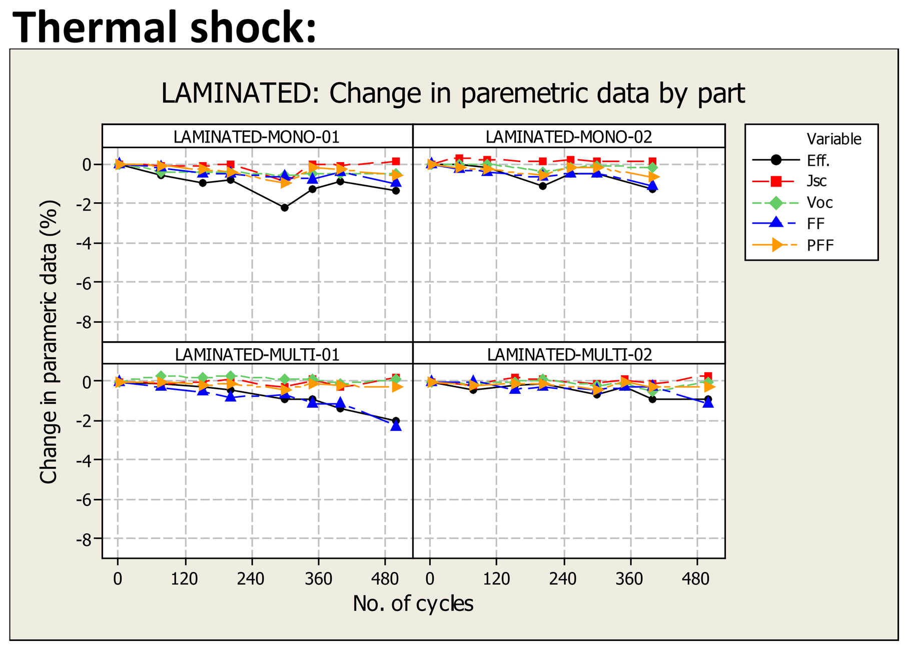
IV performance—bare strings and encapsulated modules

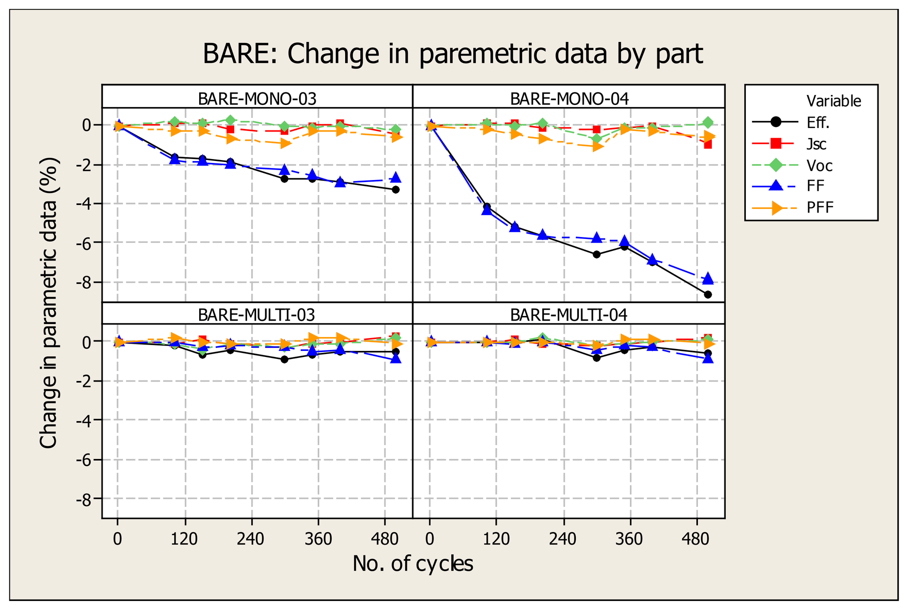
For comparison, both multi- and mono-crystalline cells were fabricated into modules. For the bare strings, the mono- cells show areas of GICS induced micro-cracks (Grid Interruptions Caused by Soldering)[2] in the EL images whereas the multi-crystalline cells do not (see discussion in Analysis section).

Despite the significant decrease in peel strength and increase in GICS, the electrical performance of bare strings shows only a modest change in performance for both 400 cycles of thermal shock and 60hrs of HAST (see plots below). For HAST exposure, the performance change was less than 1% despite a reduction in peel strength of >95%. In the case of HAST testing, although the peel strength is lower than thermal shocked samples, the stress on the interface is also less since the samples are exposed to an isothermal environment closer to the zero stress condition observed at the soldering temperature.

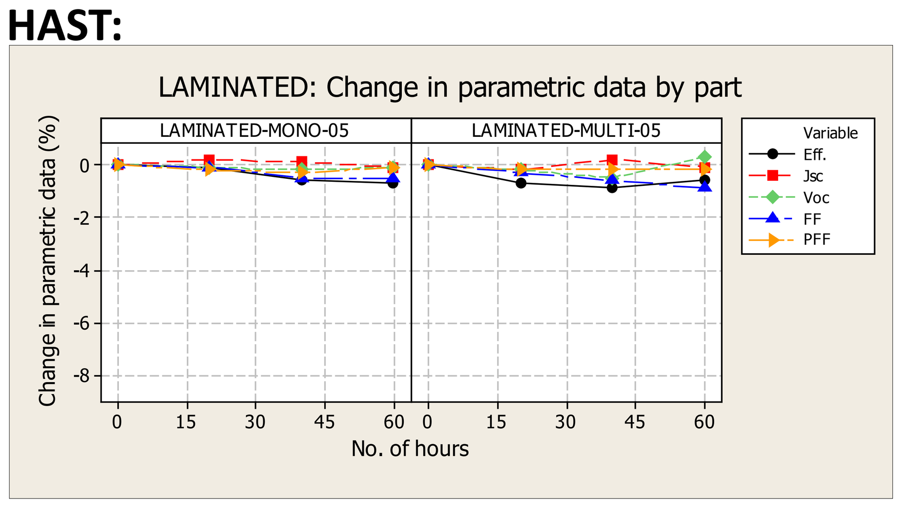
As expected, all laminated samples show good performance during thermal shock and HAST with all modules well within the IEC -61215 specification of 5% degradation both at the test requirement of 200 cycles and beyond.

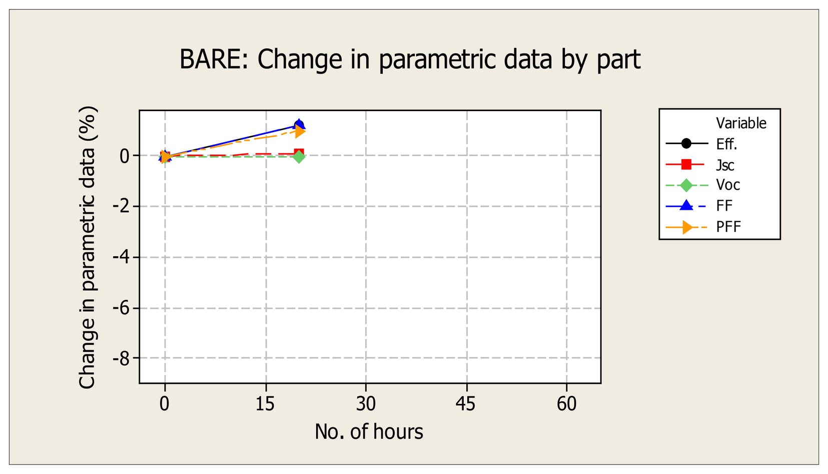
Thermal shock:





HAST:



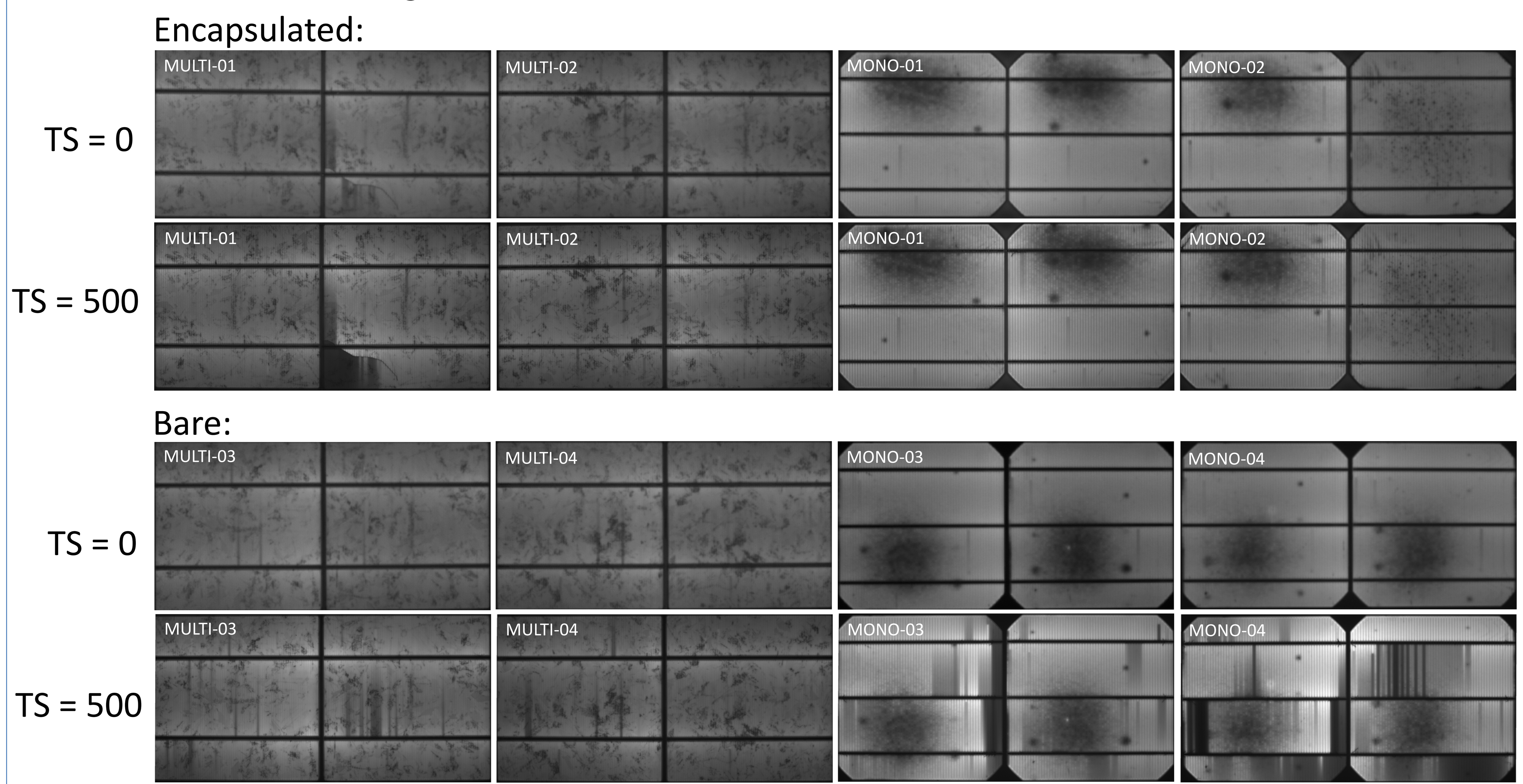


Analysis

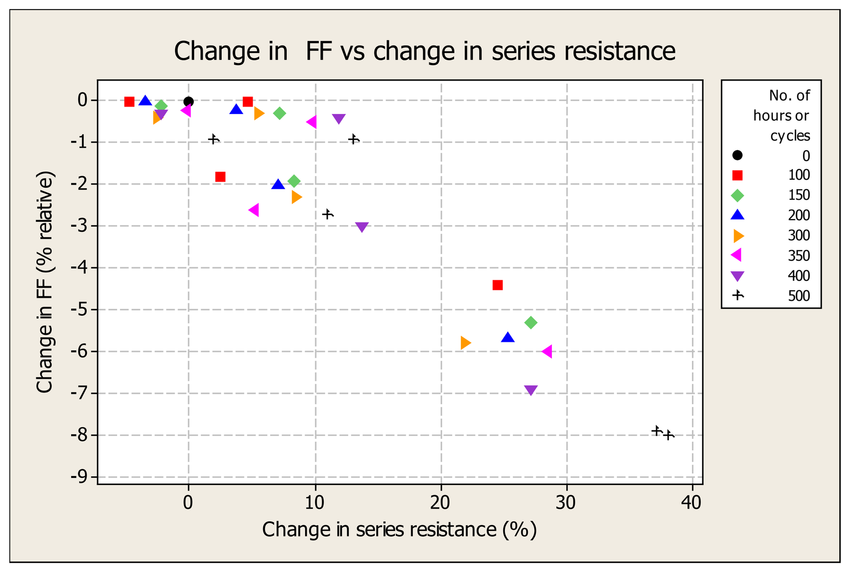
The electroluminescence images below show a clear difference in GICS between bare multi- and mono-crystalline cells. Typically, we have observed that multi-crystalline cells are more susceptible to GICS than mono-crystalline cells. However, as noted by Wiese et al,[1] interconnection stresses are sensitive to the ribbon/busbar width ratio. For this study, the same 1.5mm wide ribbon was used for both the two busbar multicrystalline and 3 busbar mono-crystalline cells but the busbars were 2mm wide for the multicrystalline cells thereby reducing the peak stresses in the joint.

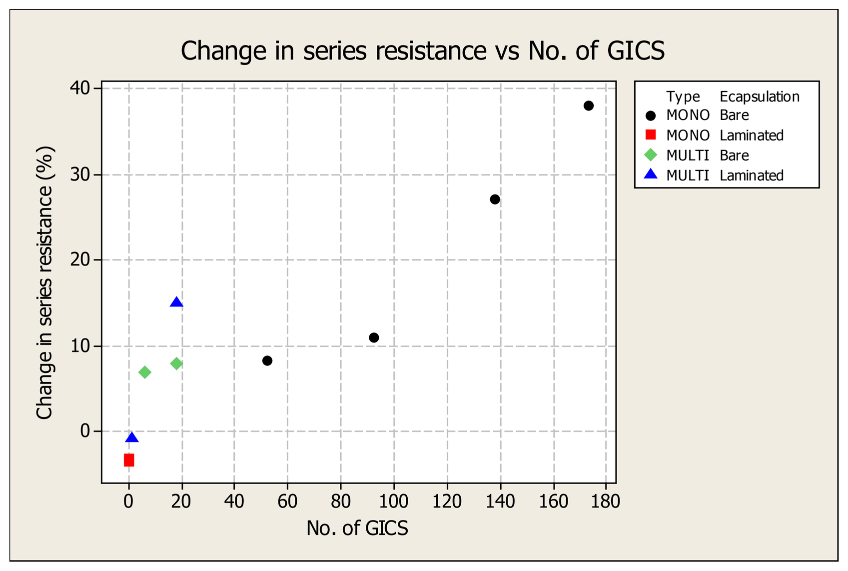
In addition, the electroluminescence images show no GICS for either the laminated mono-crystalline or laminated multicrystalline cells confirming that the laminate provides additional compressive force on the interconnects ensuring good electrical contact during both reliability testing and outdoor exposure.

Electroluminescence images:



It is surprising that the electrical performance of several of the samples studied here is maintained despite a dramatic degradation in peel strength. For the modules that did show degradation, the efficiency drops due a drop in FF (shown in the IV data at left) and this drop in FF correlates with a series resistance increase (plot below, left) and an increase in the number of GICS (plot below, right):





Conclusions

Solar modules have successfully demonstrated many decades of failure free operation in the field. Accelerated testing shows that the industry standard laminate construction and cell interconnection is resistant to both thermo-mechanical and humidity induced failures when combined despite the individual interface connections showing degradation over relatively short test periods.

References

1. Wiese, S.; Kraemer, F.; Betzl, N.; Wald, D.; " Interconnection technologies for photovoltaic modules - analysis of technological and mechanical problems". Thermal, Mechanical and Multi-Physics simulation and Experiments in Microelectronics and Microsystems, 2010. EuroSimE. 11th International Conference on

2. J.Wendt, M. Träger, M. Mette, A. Pfennig, B. Jäckel; "The link between mechanical stress induced by soldering and micro damages in silicon solar cells". Q-Cells SE.