PV Connector Reliability
Part II: Forensics Analysis of Failed Connectors

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BACKGROUND AND MOTIVATION

- PV connectors are an integral part of a solar plant that connects solar PV modules and strings and need to have minimum resistive losses.
- Yet PV connector failure is widely recognized as a main contributor to the safety and power production of solar-based generation [1].
- Approximately 30% of PV power-plant incidents such as fires or arc-faults are due to failed junction boxes and PV connectors [2]
- One goal of this DOE-sponsored 3-year project is to gather and conduct forensic investigations on a well-pedigreed population of field-failed PV connectors to identify the underlying causes for failure.

Source: [3]

Fig. 1. Incidents showcasing examples of damage to solar PV modules and instance of fire in a solar station resulting from connector failures.

BASELINE STUDIES OF OFF-THE-SHELF CONNECTORS

- Objective: Metallurgical analysis of commercially available off-the-shelf PV connectors establishes variability in metallurgical design and coating characteristics among connectors from different manufacturers.
- Methodology: Metallic pin and sleeve components are prepared using standard metallurgical preparation procedures. Fig. 2 shows connector components and sectioning scheme (*left image*) and an example of polished cross section of metallic connector components (*right image*).

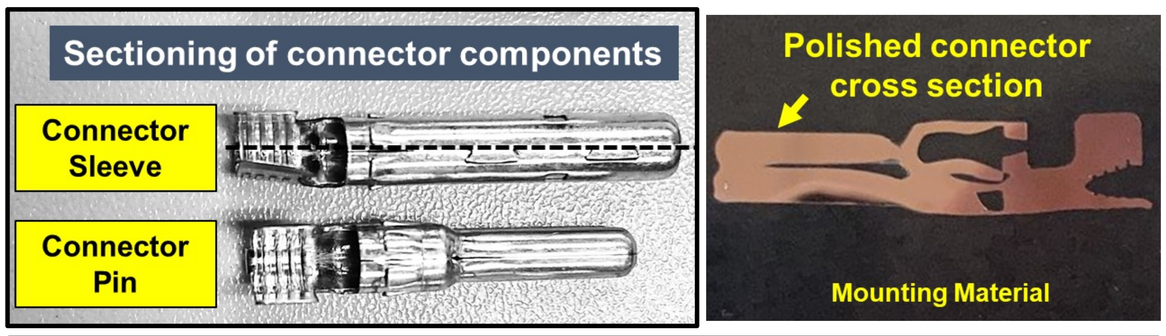

Fig. 2. Typical image of a connector cross-section after metallographic mounting and polishing

PRELIMINARY FINDINGS

- Analysis of off-the-shelf connectors shows noticeable variations in connectors from different manufacturers.
- Fig. 3 compares the structural characteristics of the surface coatings on connectors from three different manufacturers. Some connectors show a multi-layered coating structure adherent to substrate (*Fig. 3 – images a and b*), others show a lack of coating structural integrity (*Fig. 3 – image c*). The coating layers may be necessary to protect the metal pin from environmental conditions that lead to corrosion so the diagnosis of variability and defects is important.
- Fig. 4 shows elemental analysis of the multi-layered coating structure for one connector. The coating layers have a Tin (Sn) outer layer that is separated from Copper (Cu) substrate by a Nickel (Ni)-rich interlayer. The interlayer is also enriched in Nitrogen (N). The Tin layer also shows enrichment in Oxygen (O).
- Differences in coating composition and deposition may cause differences in long-term performance of PV connectors in field

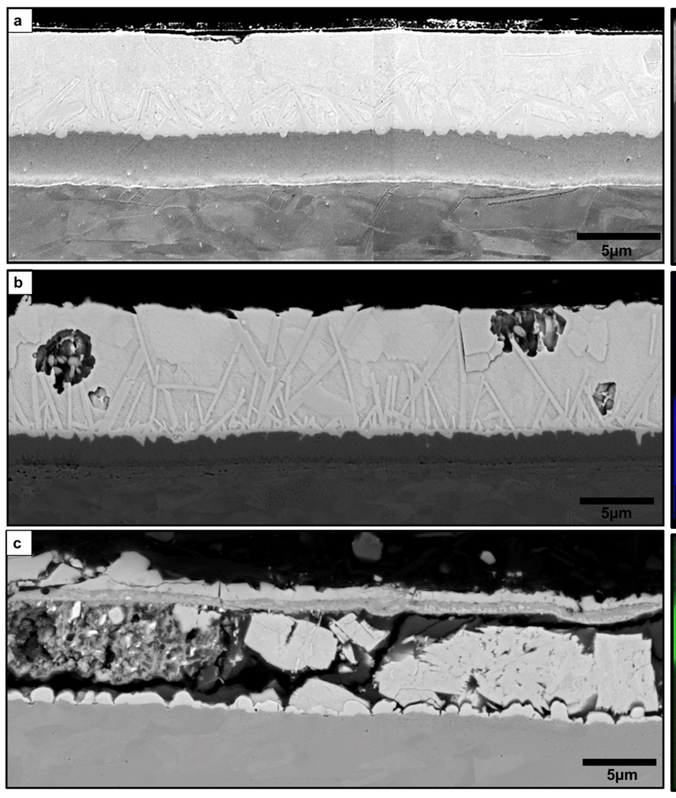

Fig.3 Surface coating characteristics of off-the-shelf connectors showing differences in structure of coatings

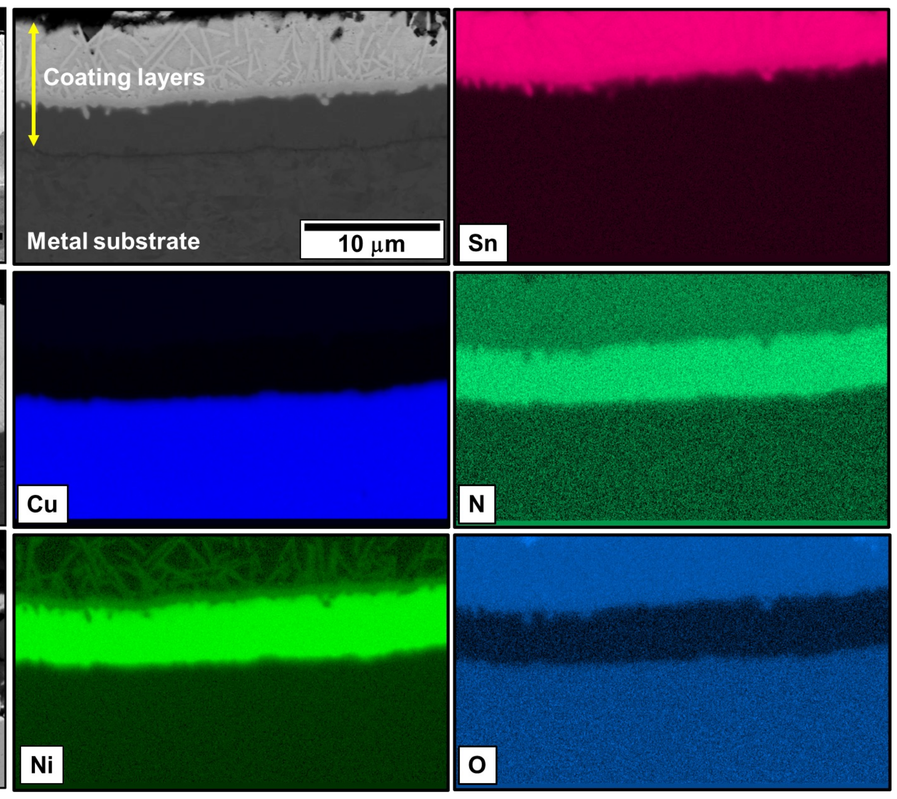

Fig.4 EDS analysis of surface coating layers showing a multi-layered structure consisting of a Ni-rich base layer and a Sn rich top-layer.

NEXT STEPS IN OUR FAILURE ANALYSIS

- Aggressive expansion of our collection and analysis of field-failed connectors, including those identified to be on the verge of failure due to high operating temperatures or that have failed in the field (*see* PV Connector Reliability, Part I poster).
- Refinement of our methodology to enable the inspection of internal components, despite macroscale deformation, without destroying evidence in the interior of the connectors and hidden from view.

Fig.5 Example of a field-failed connector collected for forensic analysis

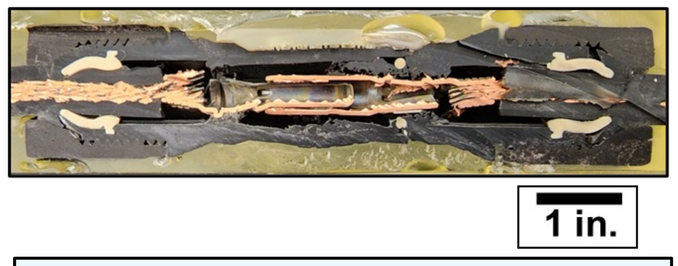

Fig.6 Section of a failed connector showing interior portions for forensic analysis.

REFERENCES

1. The ultimate safety guide for solar PV connectors, PVEL, 2022
2. S. Namikawa, "Photovoltaics and Firefighters' Operations: Best Practices in Selected Countries." International Energy Agency. Report IEA PVPS T12-09:2017
3. "The Consequences of Ignoring the Quality of Solar MC4 Connectors are Disastrous" (www.slocable.com.cn/news/)

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