Connector Failures: Field and Lab Findings

Micro-level forensics

Connector Reliability Across the US Solar Sector

SETO CPS Agreement # Sandia 38531 and NREL 39035

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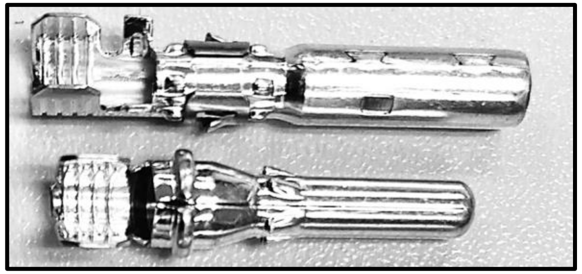
Micro level forensic analysis - Task breakdown

Part 1: Baseline characterization



Sleeve/ socket

Pin

Establish baseline characteristics of off-the-shelf metallic interconnects

- ❑ Connectors from different manufacturers studied
- ❑ Structure and composition of connectors investigated
- ❑ Coating characteristics of connectors explored

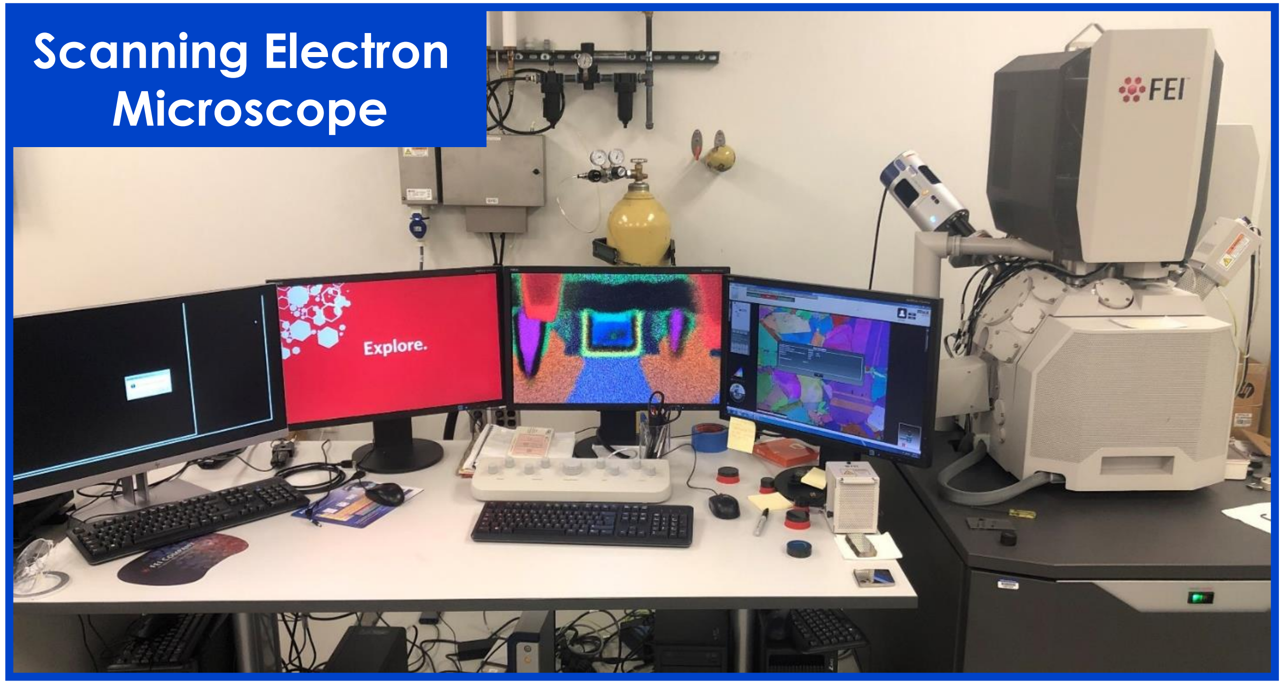
Part 2: Analysis of failed/ near failure connectors

Field harvested connectors that are near failure (still conductive)

- ❑ Method developed to prepare, and section fielded connectors
- ❑ Advanced characterization tools used to study contacting surfaces
- ❑ Analysis of coating structures near contacting surfaces

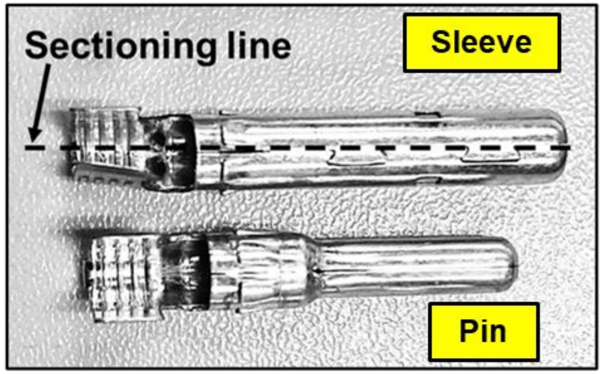
Tools for micro-level forensic analysis

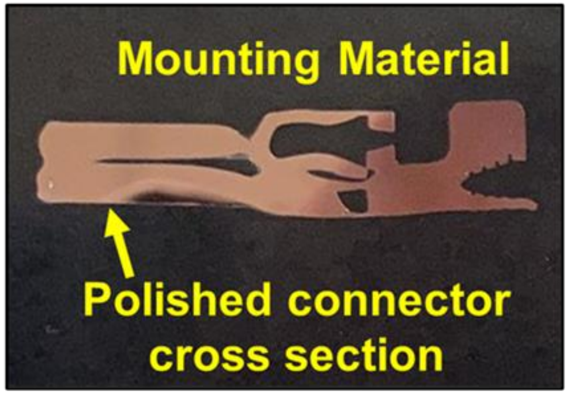
- The **Advanced Characterization Lab** at EPRI has tools to investigate materials at macro and micro length scales
- Contacting surfaces of PV connectors studied using these tools
- Examples of such tools include:
  - New generation of SEM with EDS and EBSD analytical capabilities
  - Micro-XRF for elemental mapping
  - Microhardness distribution
  - Various optical microscopes



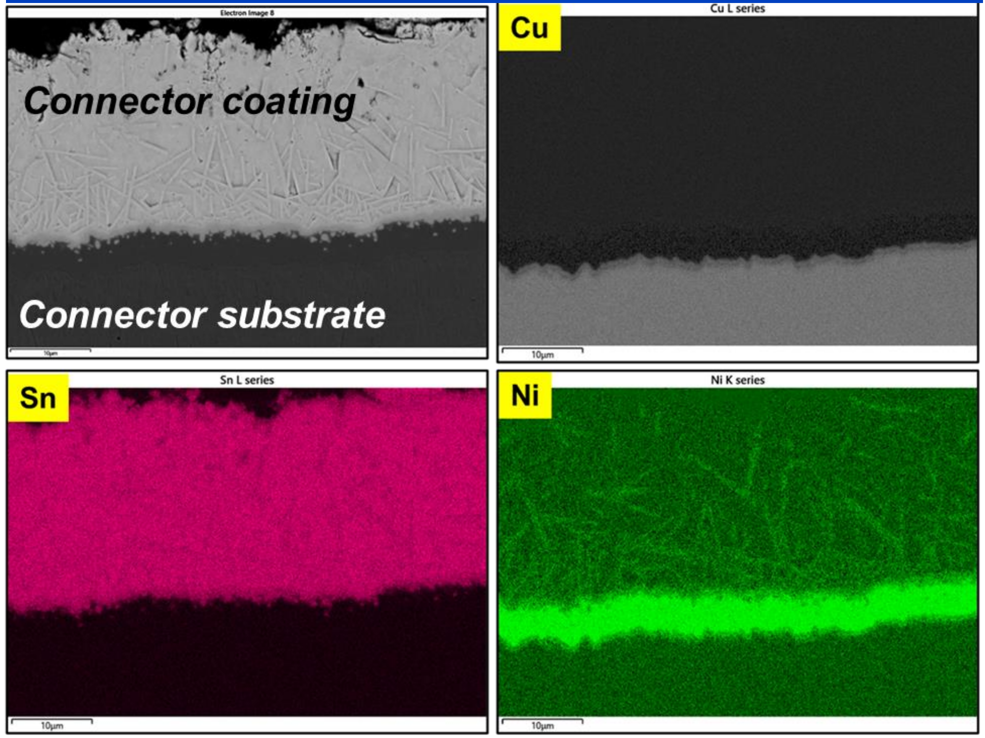
Part 1- Baseline: Analysis of as-manufactured connectors

Sample preparation

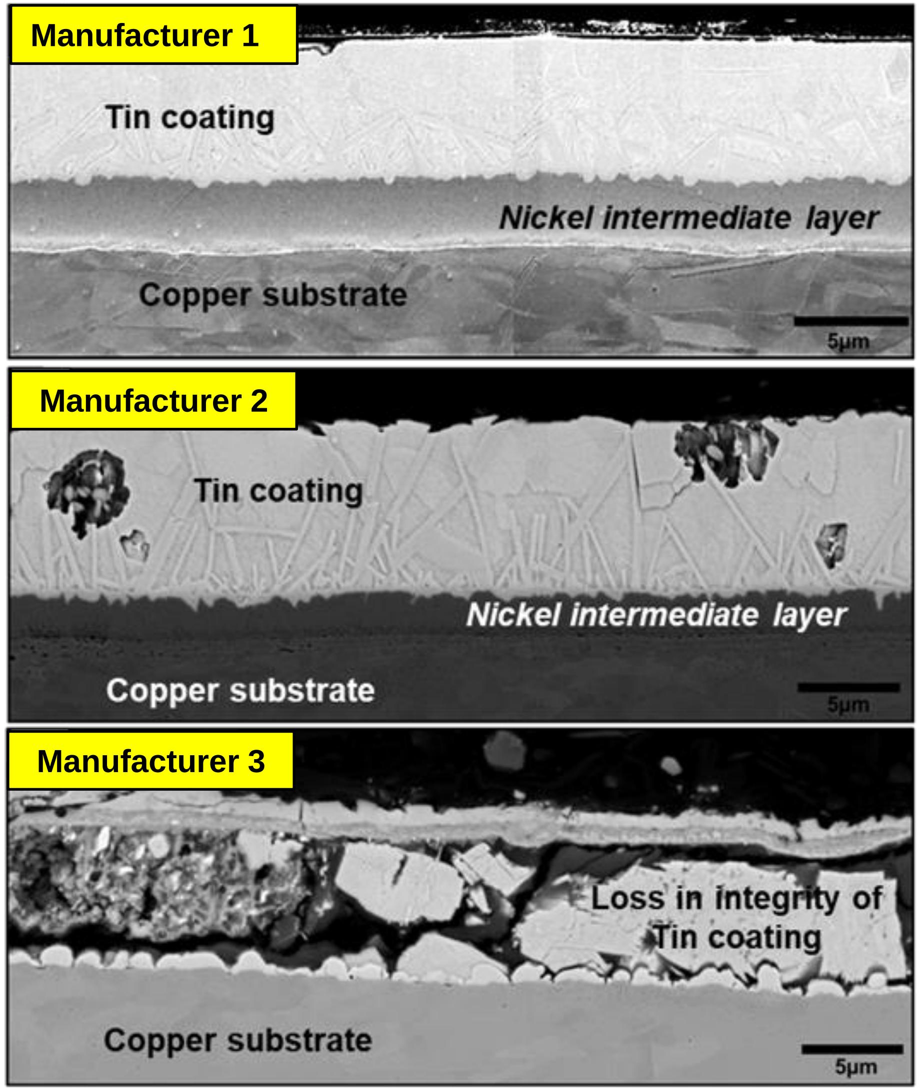




Typical coating structure shows a layered morphology with Tin (Sn) outer and Nickel (Ni) intermediate layer



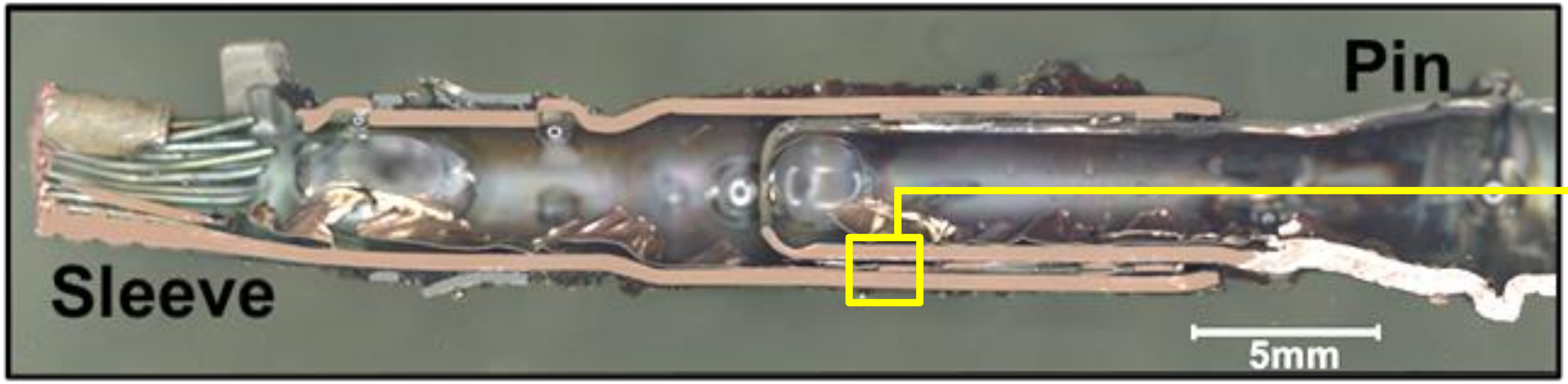
Variability in coating structures of commercially available connectors

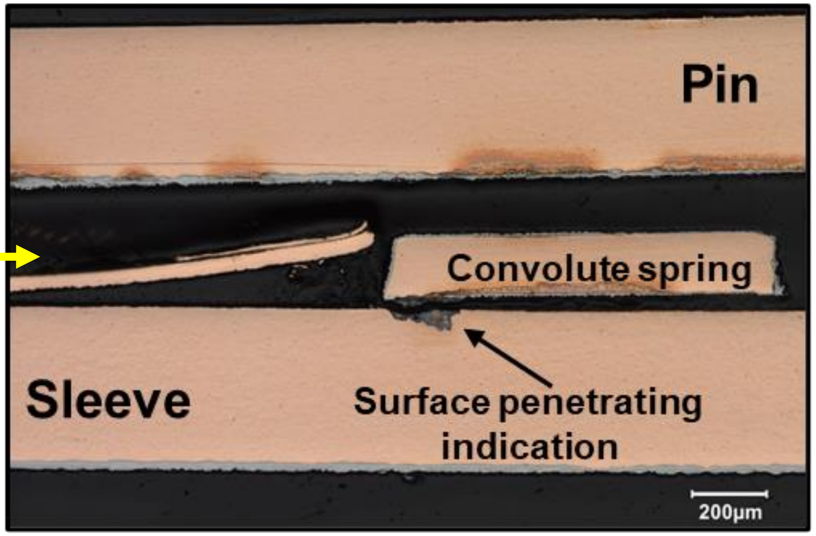


Findings from this study have shown evident variability in structure and integrity of coating layers in commercially available connectors

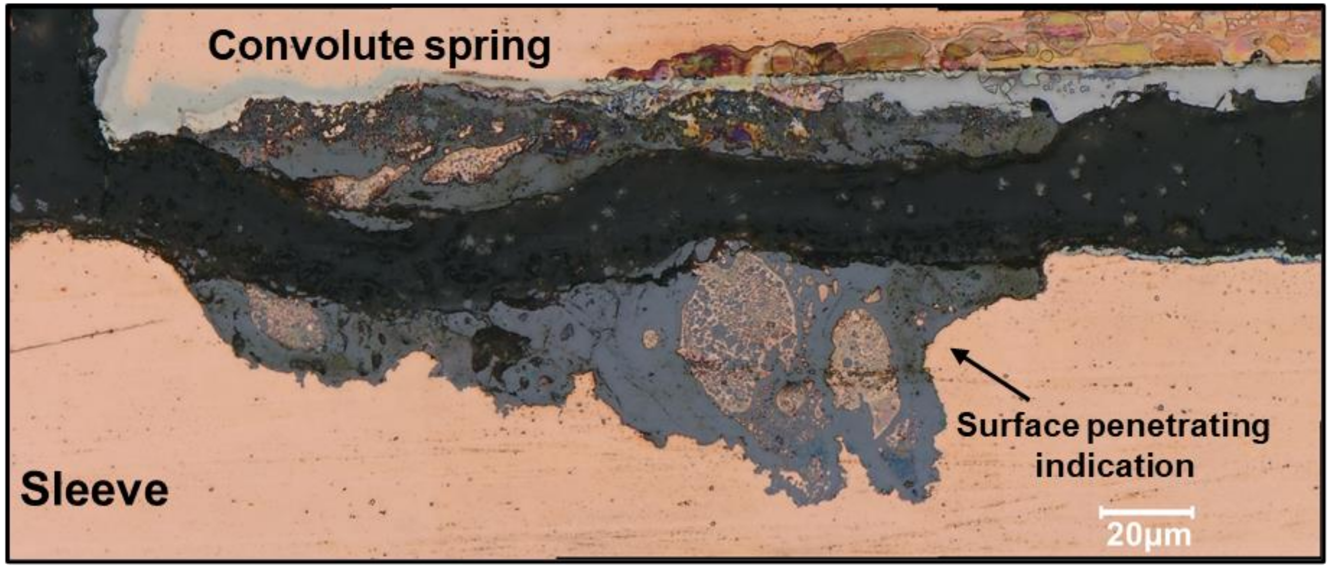
Part 2: Analysis of failing connectors

Mounted and polished cross section of connector from field



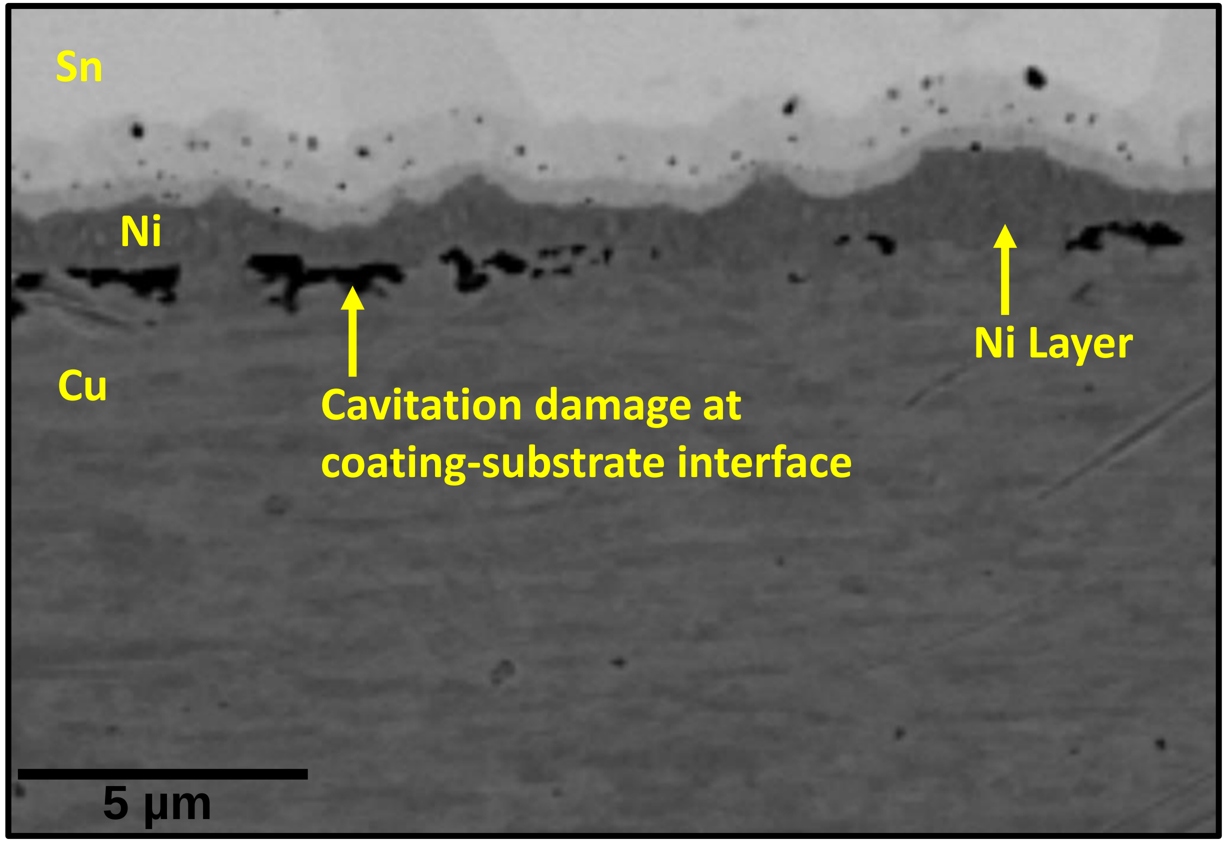


Contacting surfaces of failing connectors show signs of oxidation and local melting at contacting surfaces

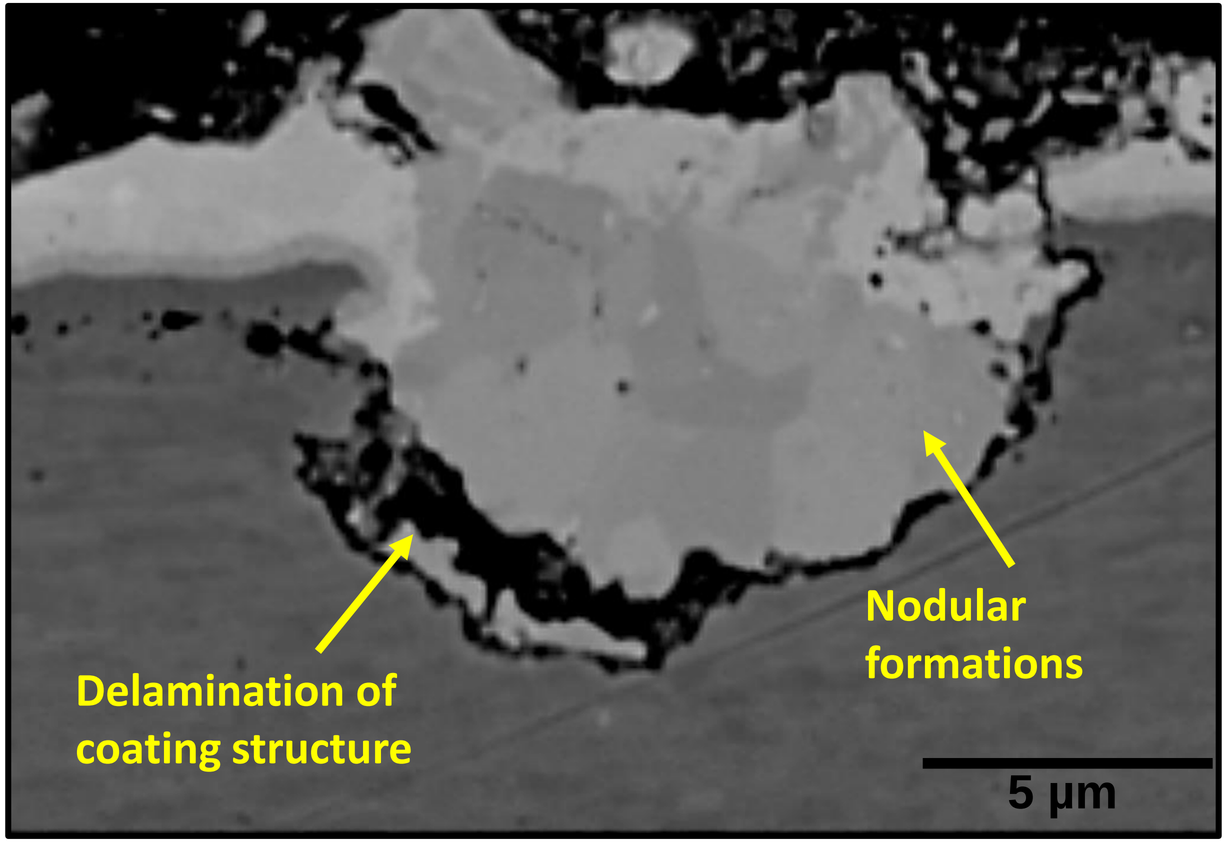


Part 2: Degradation of coating structure in field

Sub surface void formation



Thin Nickel layer and formation of nodules



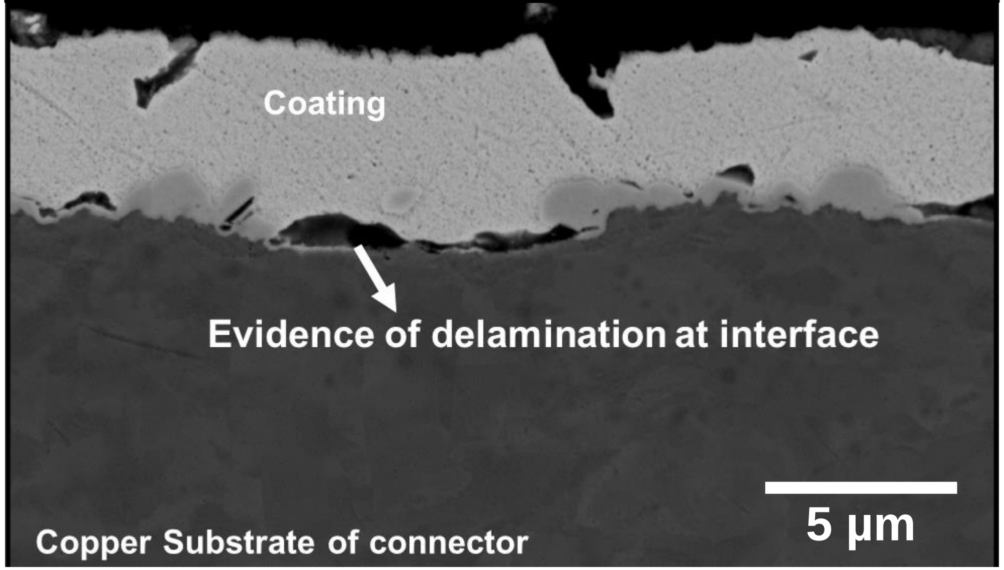
Evidence of coating degradation during service observed at contacting surfaces. Such degradation mechanism may be a precursor to sub-surface oxidation and higher resistance at contacting surfaces, leading to eventual failure

Salient findings till date

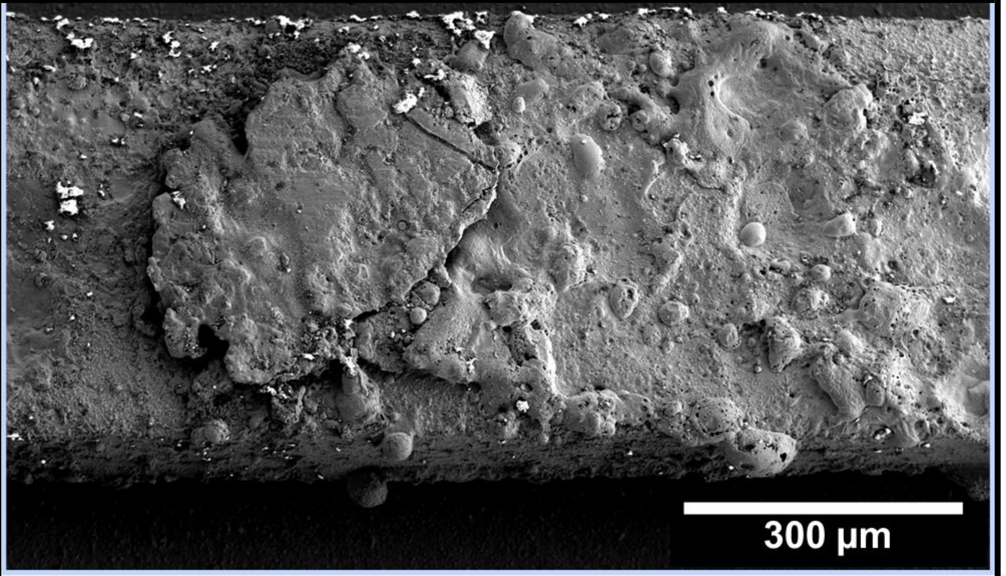
- Significant structural variations in the protective coating layers of off-the-shelf metallic connectors
  - Connectors with different manufacturers had differences in the Tin (Sn) protective coating indicating differences in manufacturing practices
  - Some connectors showed relatively poor coating adherence behavior
- Failing connectors from the field showed
  - Indications of coating degradation
  - oxidation and local melting indicating local arcing events that significantly increase temperatures

Findings suggest that understanding manufacturing practice of coating and its degradation in service are likely important to explain cause for some connector failures in the field

Structure of coating layer



Evidence of local melting in failed connectors



Summary and need for further analysis

- Issue of connector cross-mating in the field has received significant attention
  - widely considered as a major contributor to connector failures in field
- However, no clear studies have been performed to explain why such a practice could lead to failures
- **Metallurgical analysis of failing connectors is needed to understand the underlying mechanisms of such failures**
  - Structure of coating surface could be one factor that may play an important role in determining whether a connector may fail in service

Ongoing/ future work

- A small study for documenting the surface coating characteristics of a variety of connectors from different manufacturers is ongoing to understanding coating structure after manufacturing steps
- Additional connectors are being analyzed to investigate other pathways for connector failures

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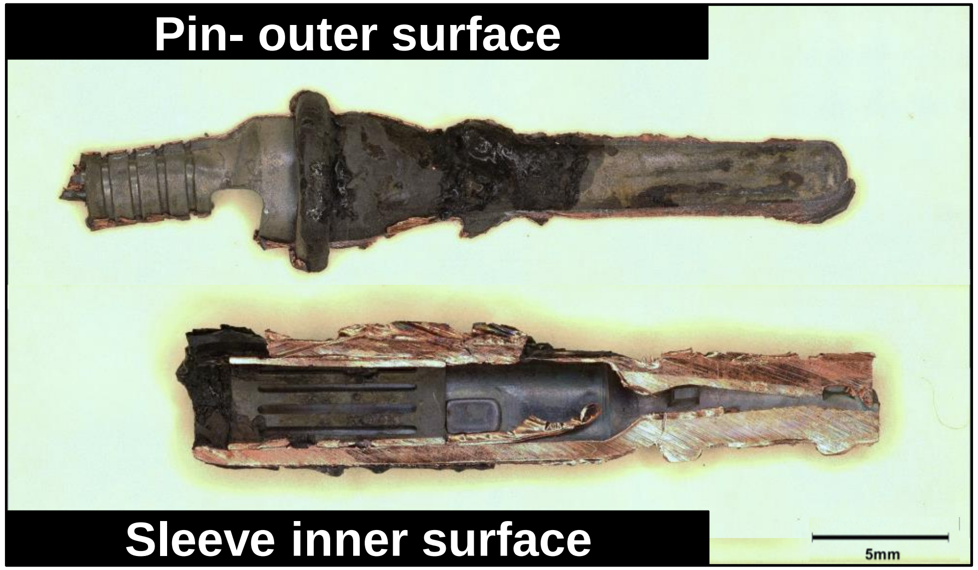
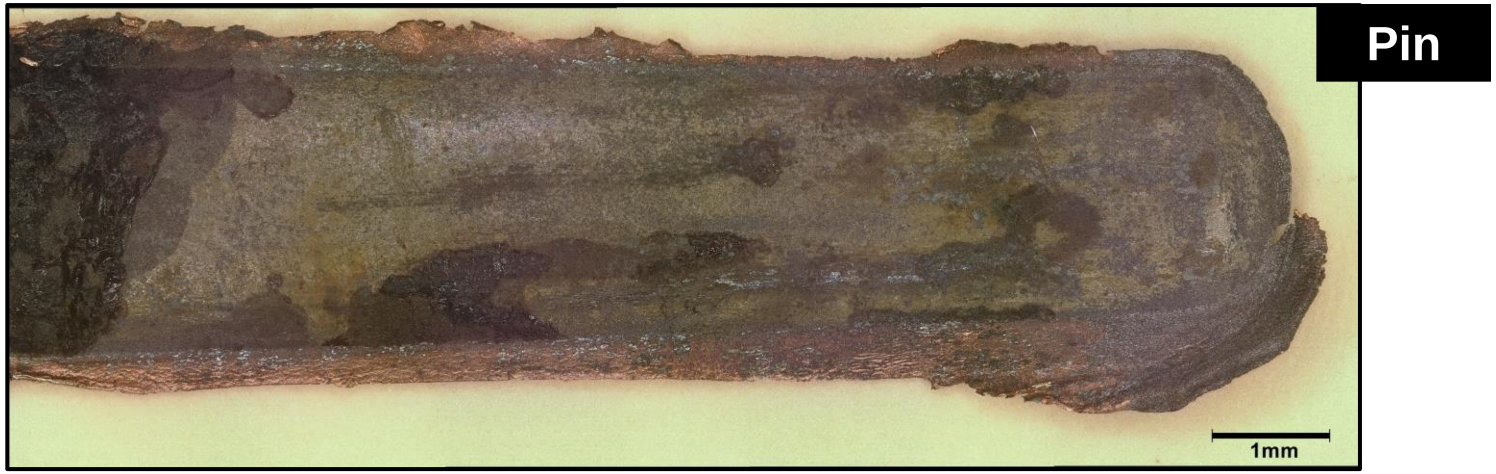
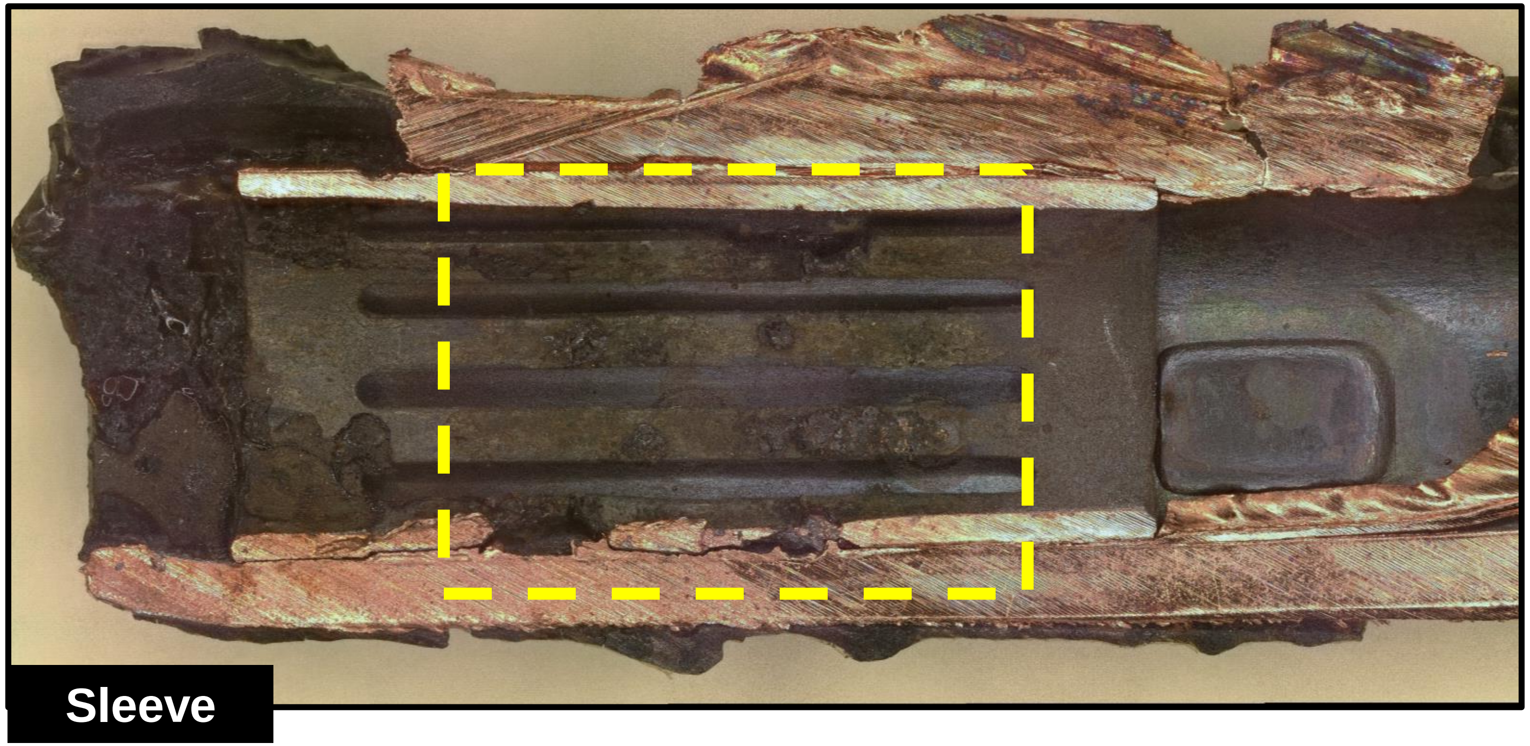
Appearance of sectioned connector surfaces







Contact surfaces of failing connectors are dull and inner surface of sleeve show presence of surface features

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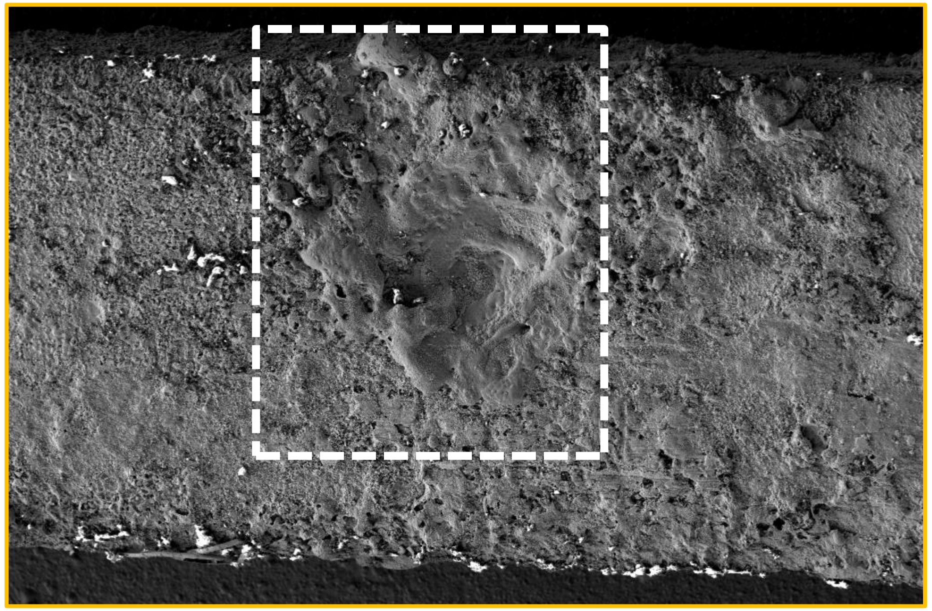
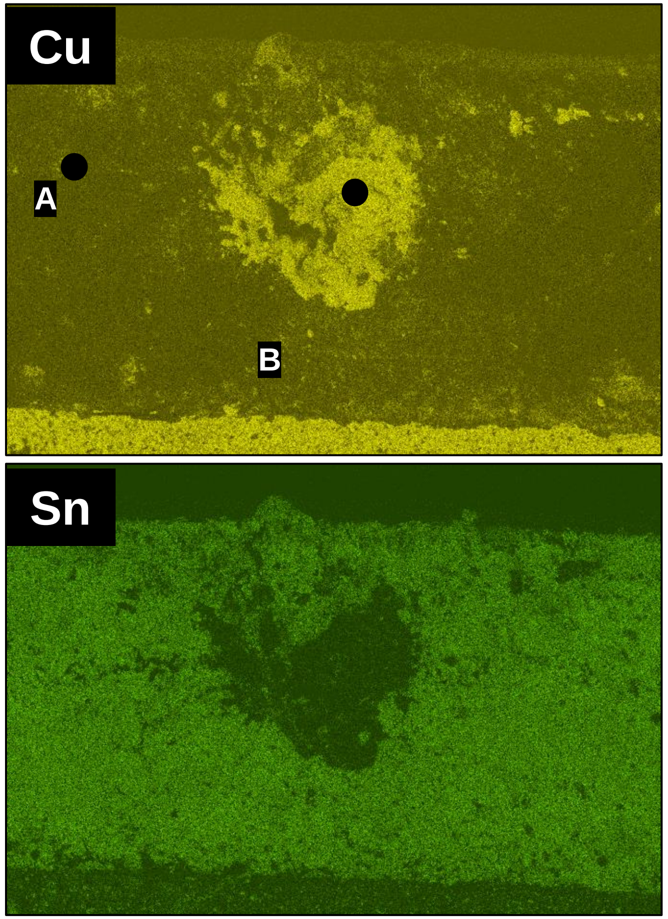
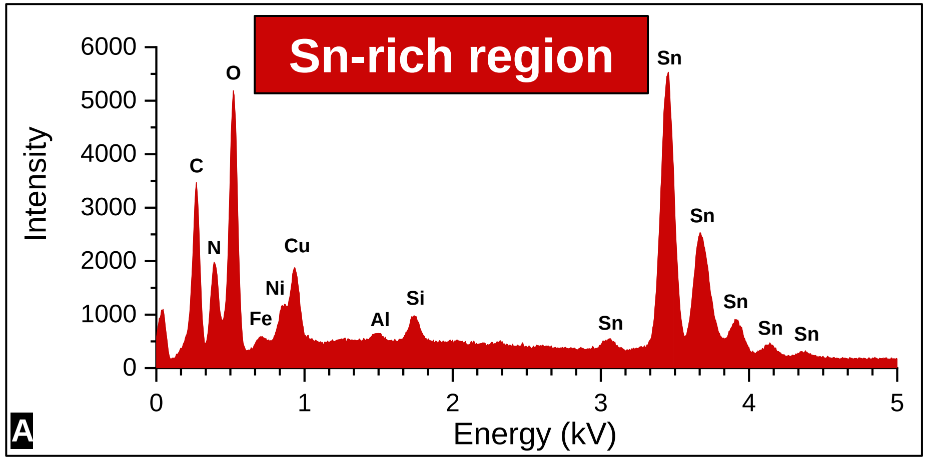
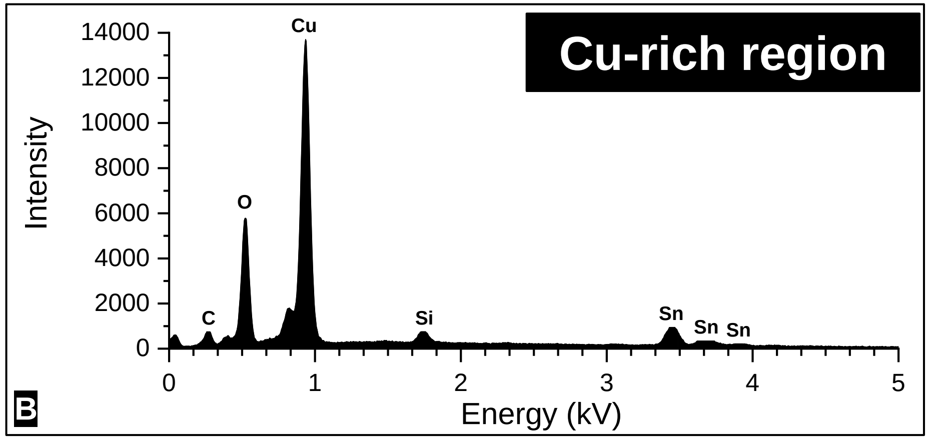
Elemental analysis of surface features show loss of surface coating due to local melting events



Sites with loss of Sn surface coating and local melting







EDS analysis clearly shows loss of Sn surface and melting of Cu (melting point 1,984°F or 1,085°C) suggesting a significant spike in local temperature

Baseline characterization: Salient findings