Review of Aerospace pre- and post-Project 1998 Tin Whisker Work

by


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Historical Perspective

– Aerospace participated in a 1998 Commercial (CCI) Project involving tin whiskers.
– All proprietary information received on that project, and all data generated including project deliverables, were only disclosed to employees who had a need to know.
– Other activities were engaged in by Aerospace, which are outside the scope of this project and, therefore, not similarly restricted, including:
  • Facilities development and facilities available for testing
  • Information obtained from the open scientific and technical literature
  • Other Aerospace projects involving similar issues
– All the information disclosed in this briefing is consistent with the above.
Summary of Prior 1992 Aerospace Work

• In 1991-1992 Dr. Frank Hai of Aerospace proved that tin and gold wires can initiate and sustain a damaging plasma.

• Configuration was a wire on end facing a plate with a vacuum in between.

• Various combinations of voltage, pressure, and plasma time, were studied, and net damage to the plate was measured.
Early Tin-Whisker Growth Models

• Dr. G. W. Stupian initially reviewed Tin Whisker growth and possible circuit effects:

• Prevailing model was that long-whiskers form at screw dislocations, consistent with a cylindrical round whisker shape, and possibly a hollow core.

• Pre-CCI 1998 work was funded by Milsatcom to verify or improve upon 1992 based information.
Pre-CCI 1998 Work Funded by Milsatcom

- Review tin whisker growth models, and recent tin-whisker associated scientific literature.
- Perform a high-resolution detailed Field-Emission SEM study of the “fluted columnar” appearance of many tin whiskers.
- Perform microscopic Focussed-Ion Beam (FIB) Cross-Sectioning of individual tin whiskers to verify if they are hollow.
- Develop an experimental facility capable of operating from atmospheric pressure down to $10^{-8}$ Torr to study plasma formation due to thin wires.
- Aim of facility was to have nearly 100% tin-plating everywhere, to maximize probability of forming a sustained tin-based plasma.
Field-Emission SEM Study Results

• High-resolution FE-SEM showed the “fluted columnar” is likely due to a 2-step process:
  – Presence of residual pressure in the tin plating, either due to residual thin-film stresses, or a chemical reaction of the tin plating with the underlying substrate.
  – Crack formation in the upper surface tin oxide layer, which allows the tin underneath to extrude out (much like toothpaste from a tube).

• The “fluted” appearance arises because the initial crack occurs at the grain boundaries edges.

• Room temperature may be high enough to allow whiskers to recrystallize during extrusion.

• FE-SEM data shows tin whiskers grow by sudden incremental jumps (like vertical tree ring growth).
Example of a Tin Whisker Cluster

Example shows Tin Whiskers as thin as 1 µm
Whiskers are Not Always Straight
Fluted Whisker Popping Up from Grain
Future Whisker Arising from Grain Boundaries
FIB Cross-Sectioning Results

• FIB Cross-sectioning of a single tin whisker verifies that they have solid interiors, nullifying the screw dislocation model of formation.

• FIB Cross-section of a whisker at its base verifies an increasing pressure gradient from the surface down to the tin-substrate interface.

• Tin-substrate reactions can often form disordered intermetallics, where volumetric expansion of the compound could create underlying pressure.
Cross-Section Shows Whiskers are NOT Hollow

Note Growth Extrusion Bands Like Tree-Rings
Demonstration of Underlying Hydrostatic Pressure Effects

Initial FIB Cut Exposed Vertical Surface. Underlying Pop-Out Occurred In-Situ After <2 hrs in Chamber.
Aerospace Plasma Arc Test Facility Development

• Facility used ultra-high vacuum system.
• Developed a “Jacobs Ladder” approach to achieve the optimum geometry for plasma propagation, which requires both a high curvature for field-enhancement, and needs a flat surface for easy of plasma propagation.
• Plasma arcs also need high amperage at relatively low voltage. Requirement implemented by using 4 automotive batteries in series to give 48 Vdc.
Why a “Jacob’s Ladder”? 

- Small radius in one dimension gives high field curvature, thought to enhance sputtering.
- Long straight section aids plasma propagation, allowing fresh material to be available to feed plasma.
- But most Jacob’s Ladders were run at ambient pressure; performance at milli-Torr to nano-Torr pressure range not known.

Thin Tin Wires were typically mounted across a region with 15-25 mil gap
Aerospace Plasma Arc Test Facility Overview
Plasma Arc Test Facility Front Control Panel

With Integrated Current Sense Resistor And High Power Mercury Switch Rated at 80 Amps, DC Ser. #CF-702
Oct. 26, 1998

• First demonstration of a sustained tin plasma, generated by a single Tin-Whisker
Initial Results From the Test Facility

- During an early system test, a long duration plasma also formed that branched around our safety fuses.
- Long-duration plasma was caused by the plasma branching from the test apparatus to the vacuum chamber walls (-24V to ground).
- Shielding test apparatus from chamber ground stopped these anomalous plasma events.
- Minimum voltage to sustain a tin-based plasma thus must be < 24 V DC.
- Facility demonstrated first sustained tin-whisker generated plasma, October 26, 1998. It was initiated by a single 2 um diameter tin whisker.