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:
  - See "Tin Whiskers in Electronic Circuits" Aerospace TR-92(2925)-7, 20 Dec. 1992.
- 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.

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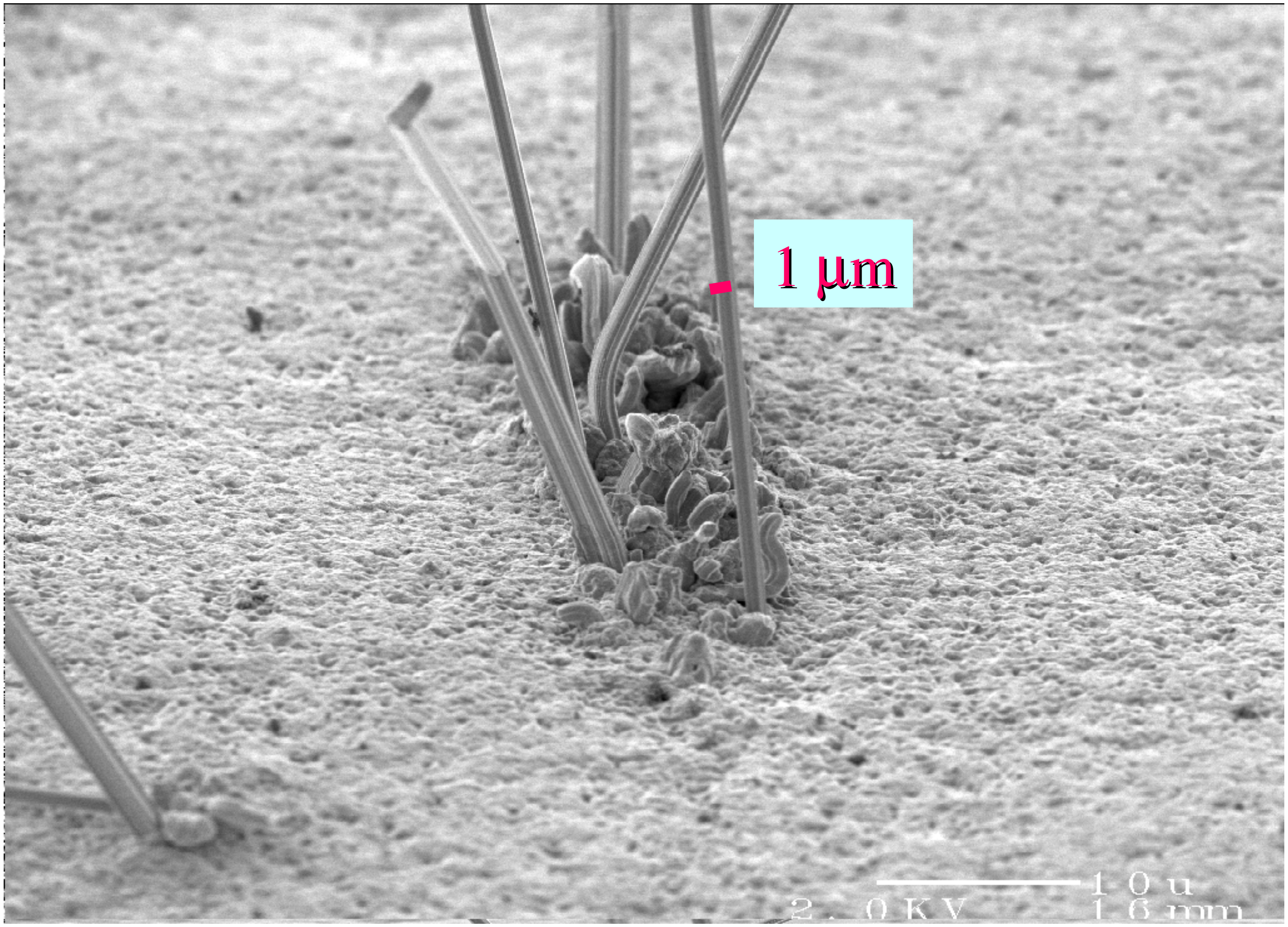
Pre-CCI 1998 Work Funded by Milsatcom

- 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

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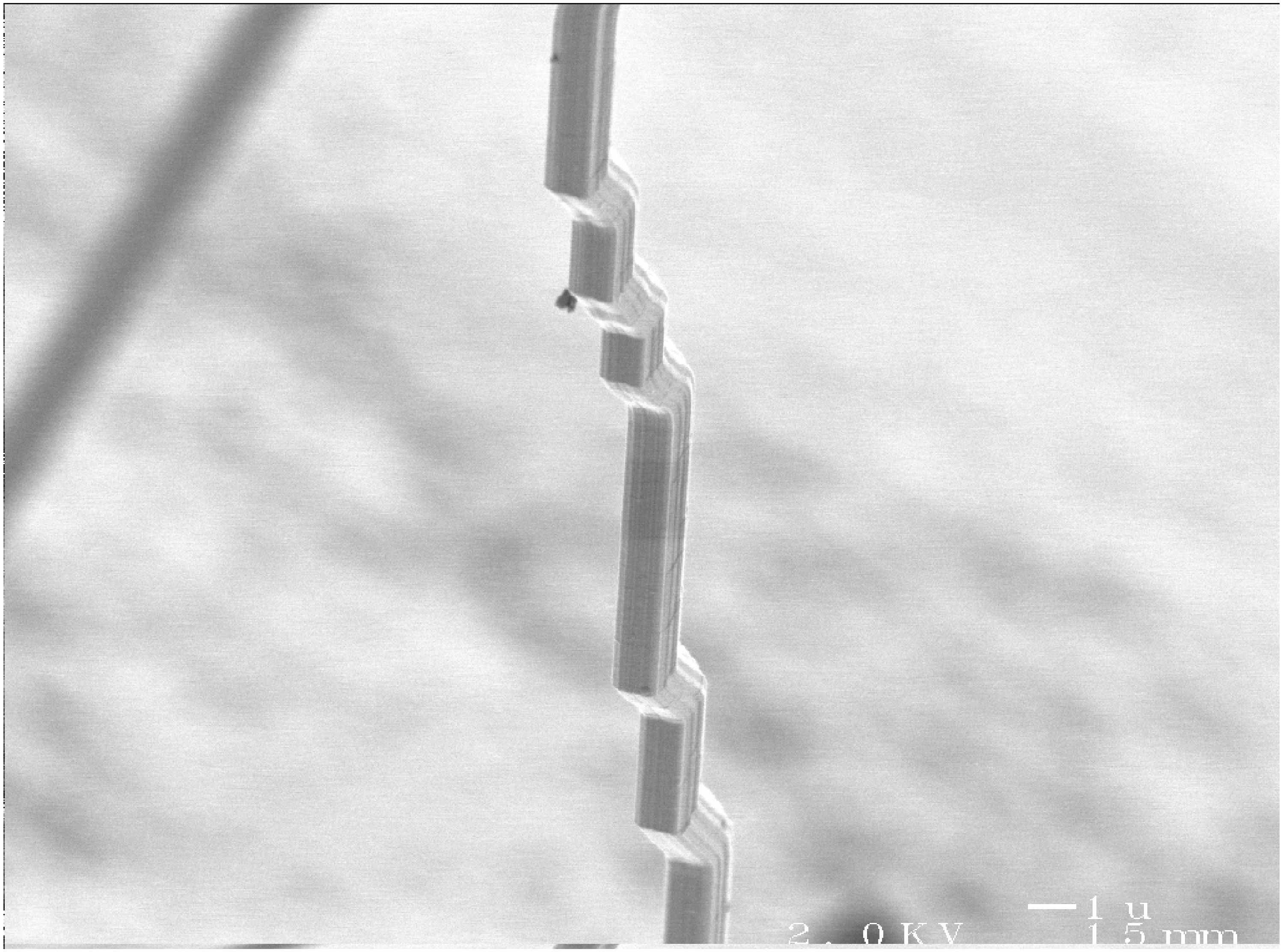
Whiskers are Not Always Straight



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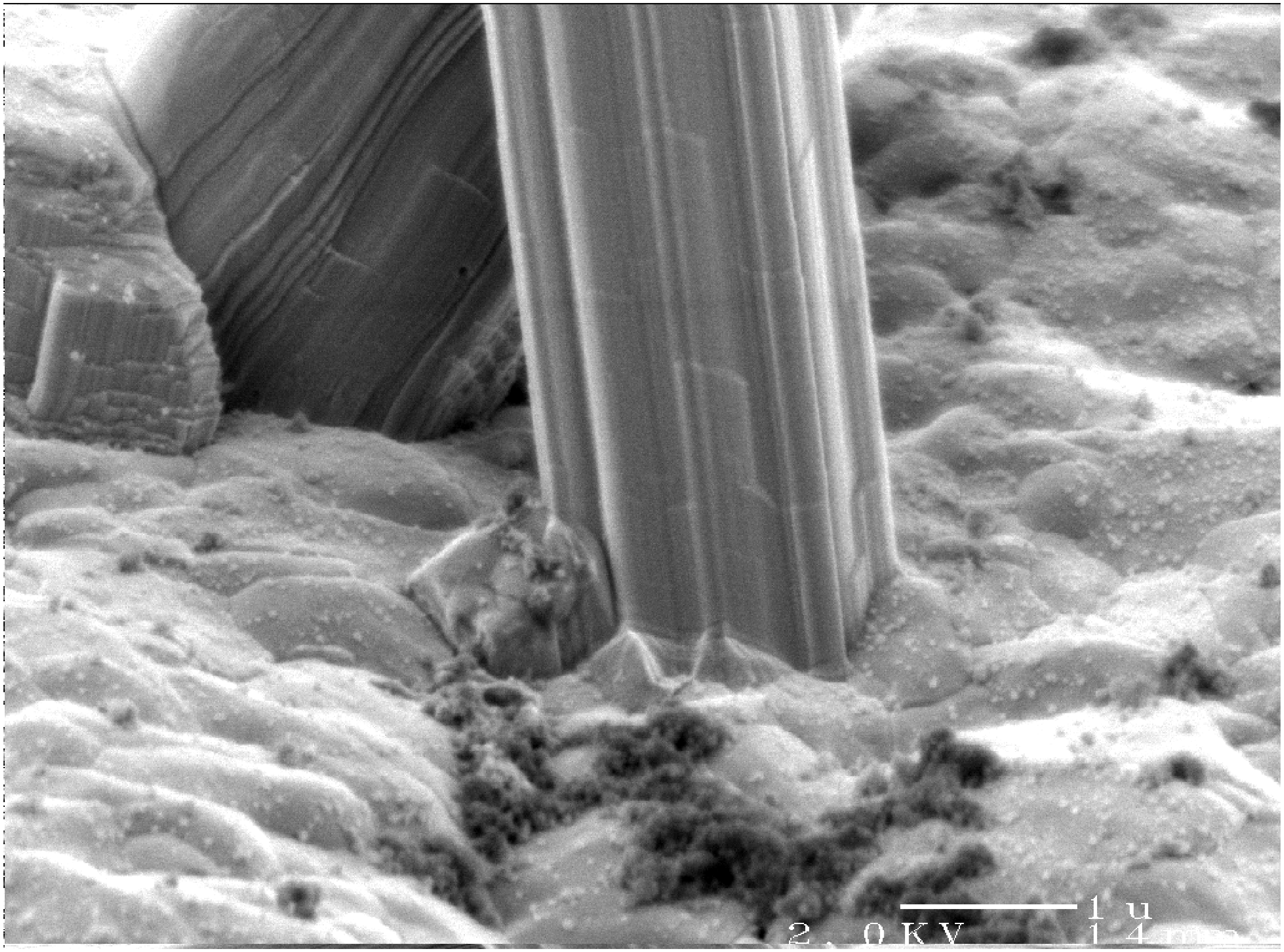
Fluted Whisker Popping Up from Grain



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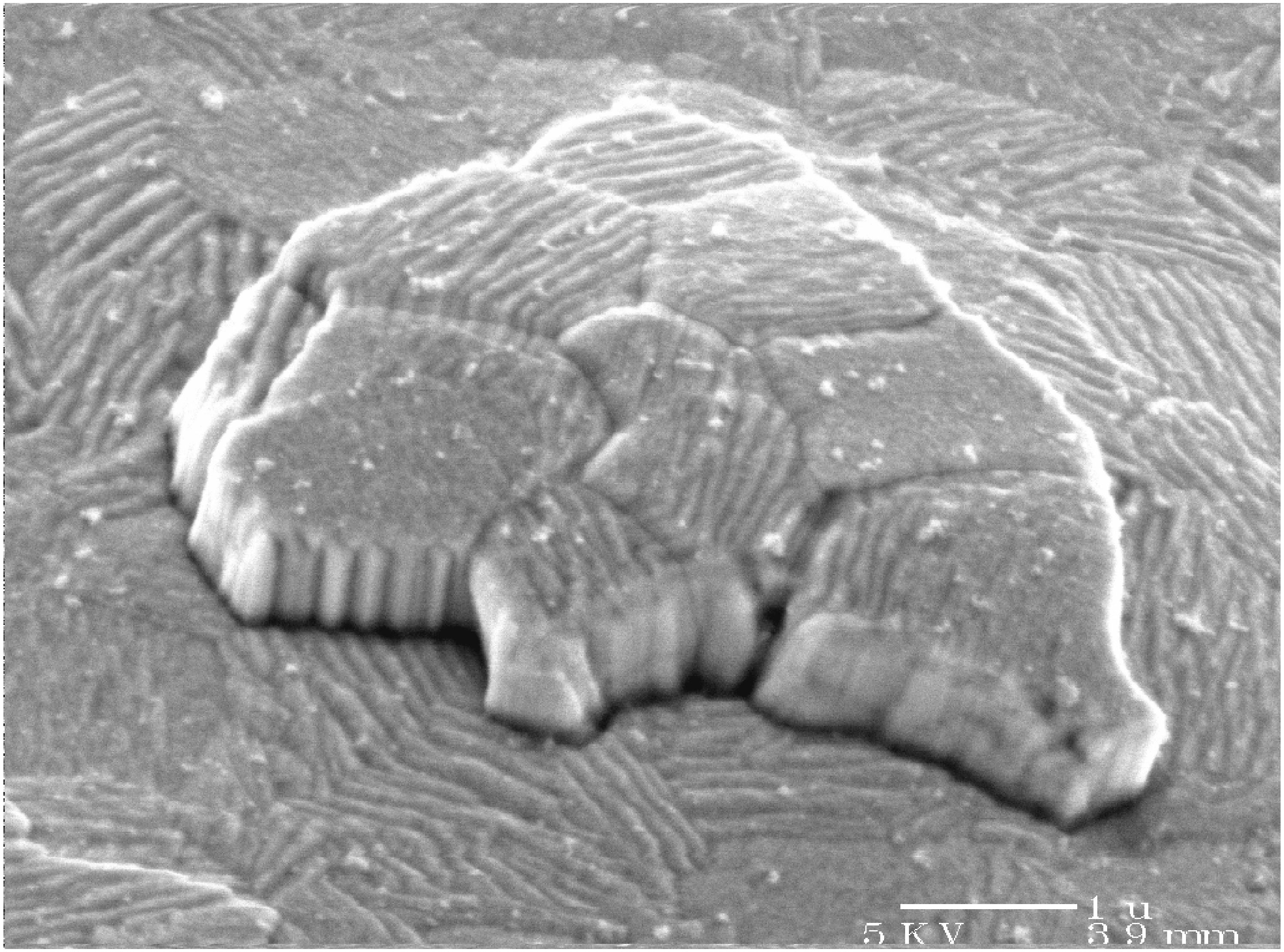
Future Whisker Arising from Grain Boundaries



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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.

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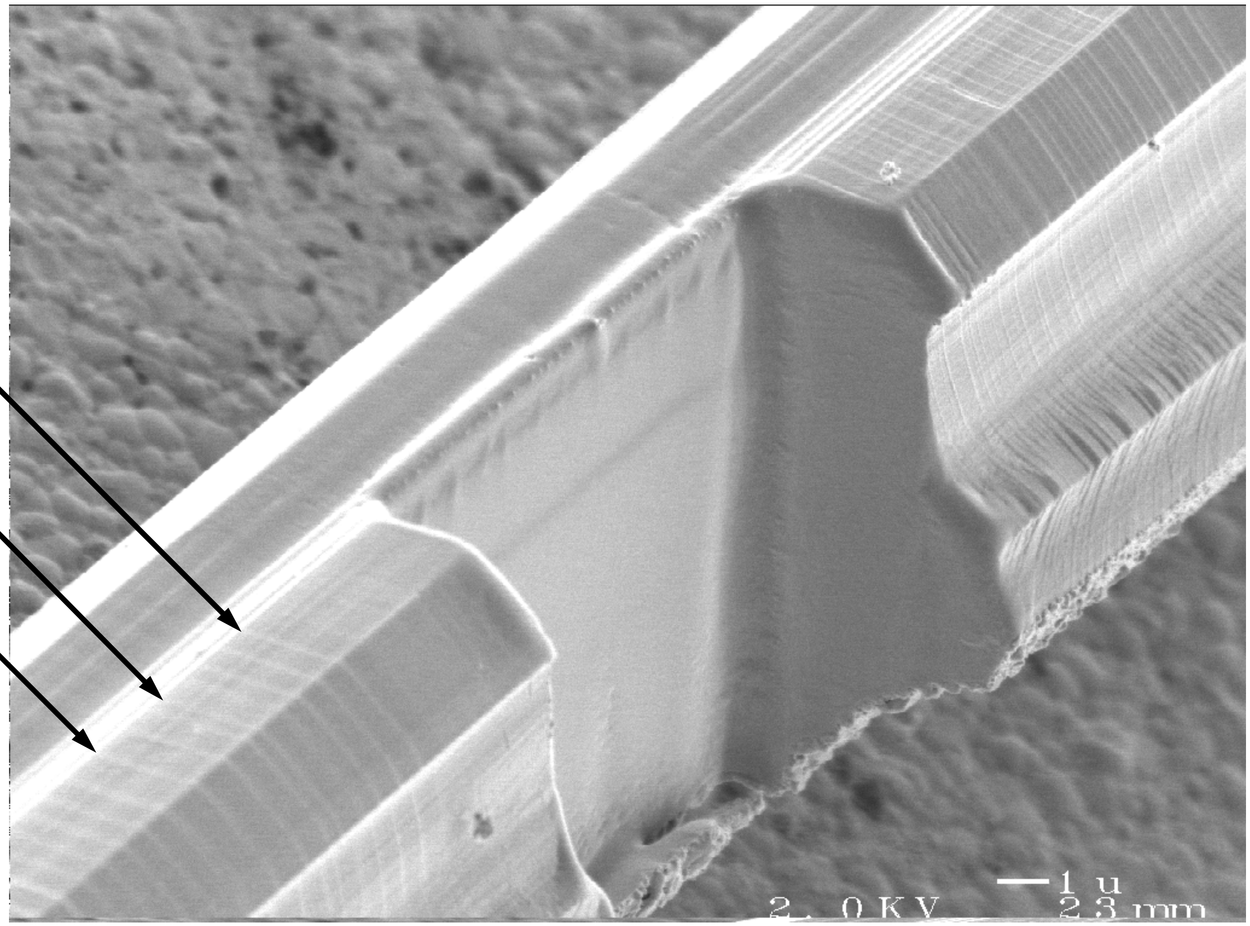
Cross-Section Shows Whiskers are NOT Hollow

Note Growth Extrusion Bands Like Tree-Rings



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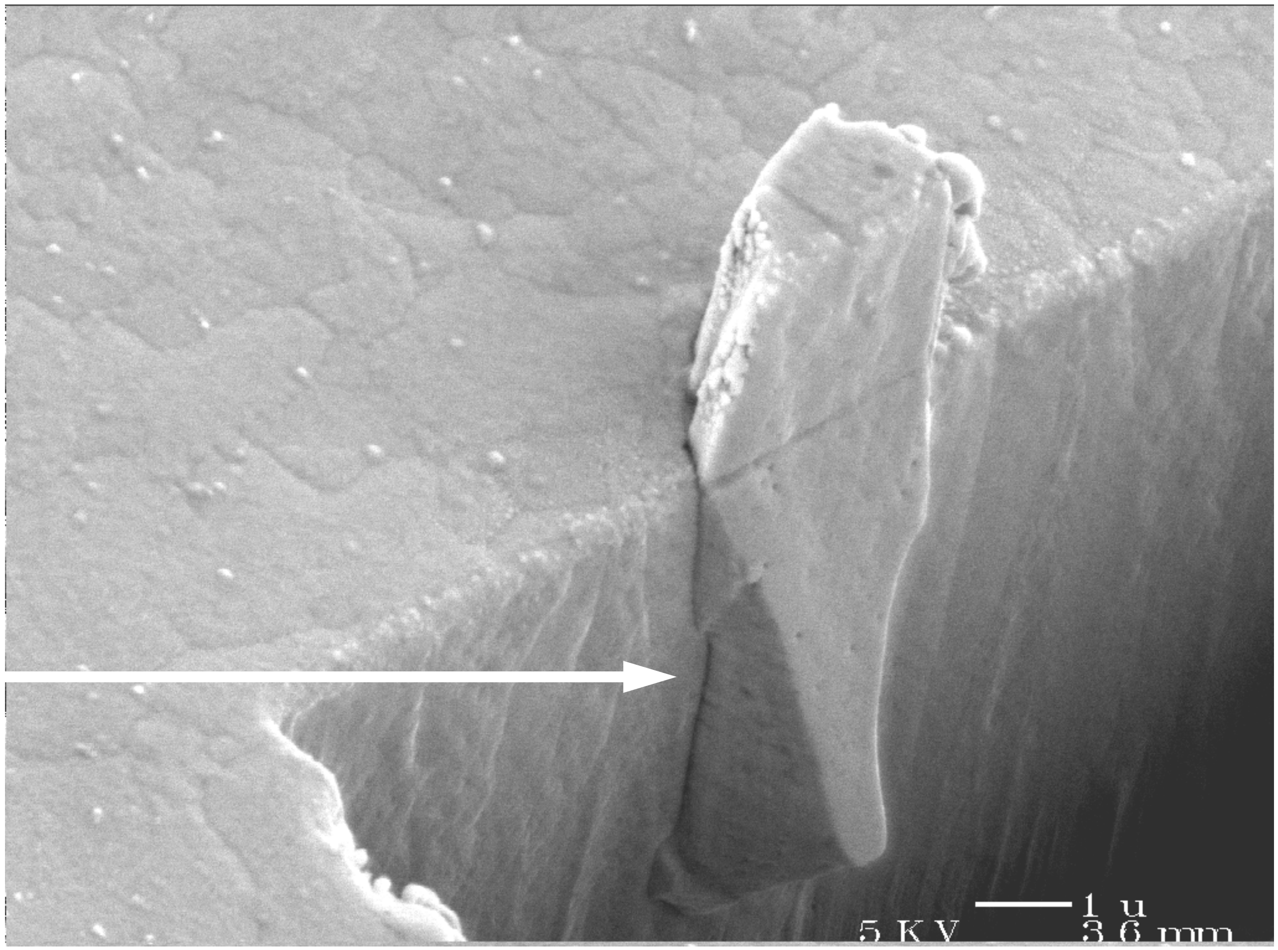
Demonstration of Underlying Hydrostatic Pressure Effects

Initial FIB Cut Exposed Vertical Surface. Underlying Pop-Out Occurred In-Situ After <2 hrs in Chamber.



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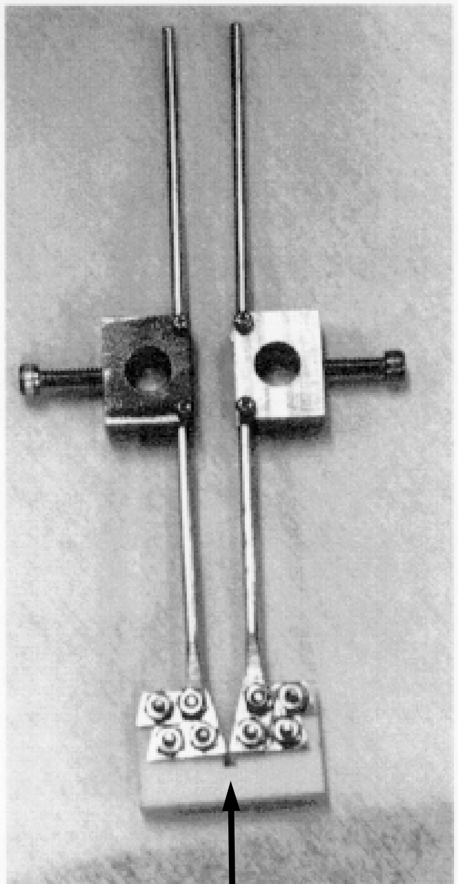
Aerospace Plasma Arc
Test Facility Development

- 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 plama.
- But most Jacob’s Ladders were run at ambient pressure; performance at milli-Torr to nano-Torr pressure range not known.

Minimum Gap ~4 mils

Thin Tin Wires were typically mounted across a region with 15-25 mil gap

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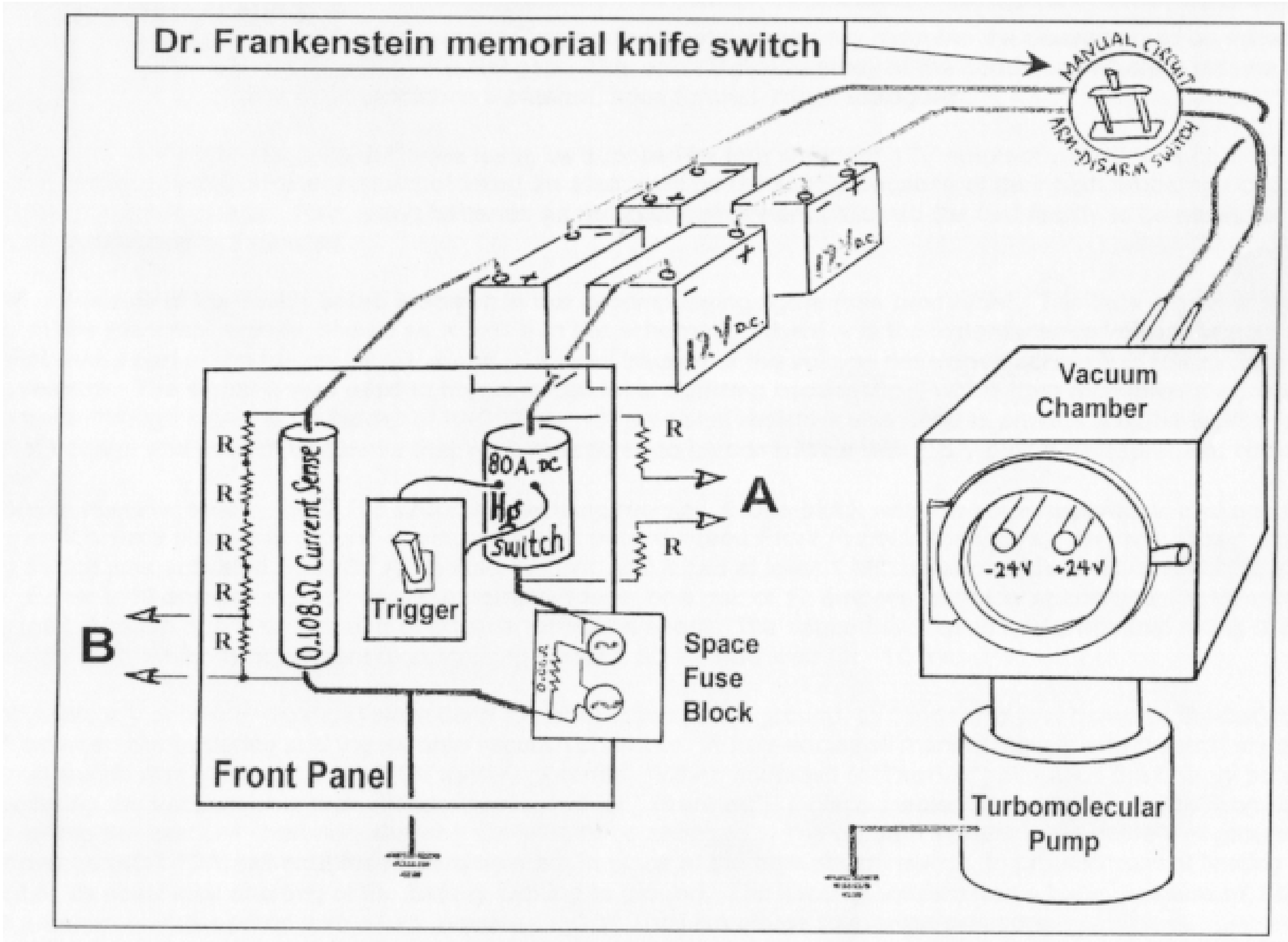
Aerospace Plasma Arc Test Facility Overview



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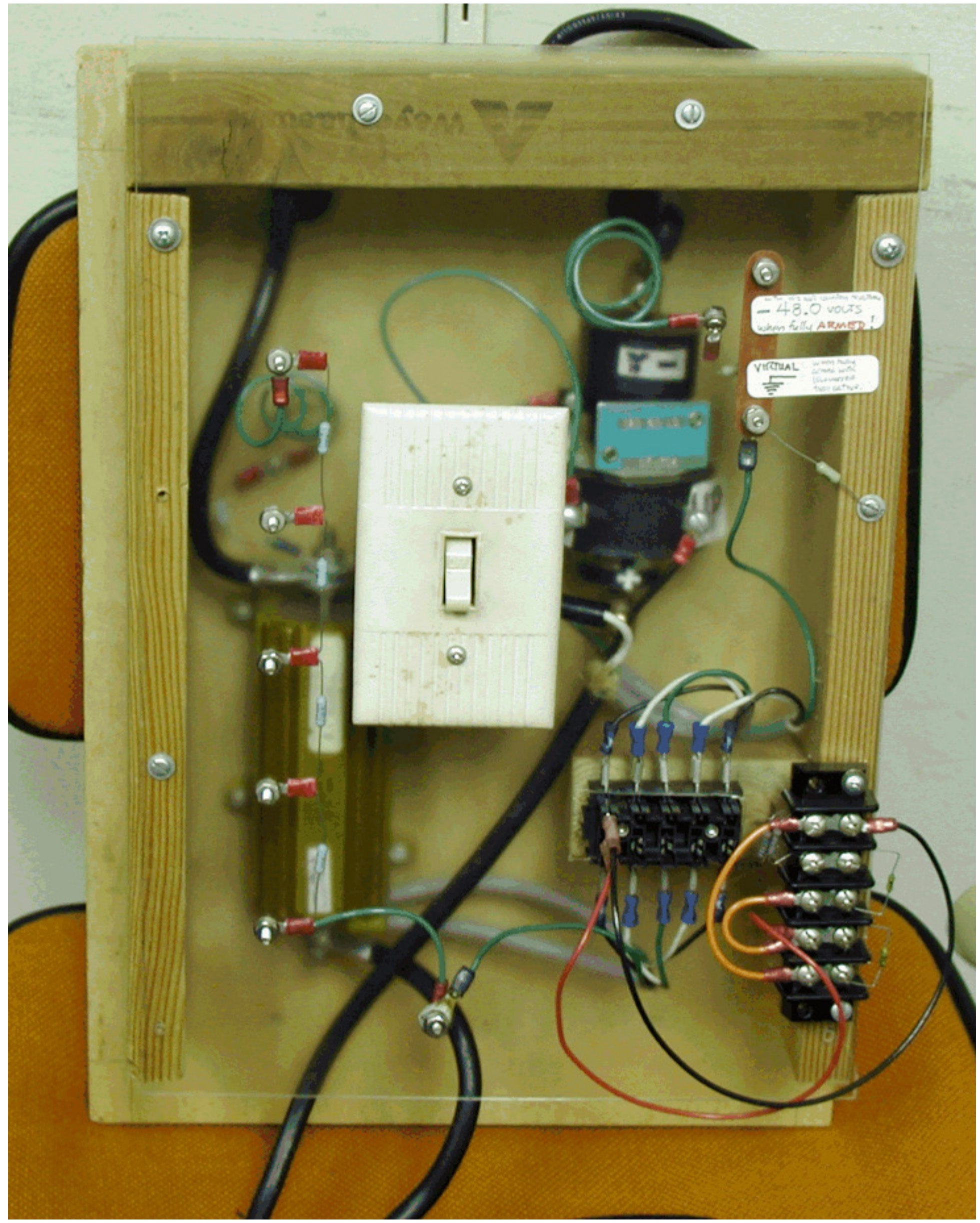
Plasma Arc Test Facility Front Control Panel

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



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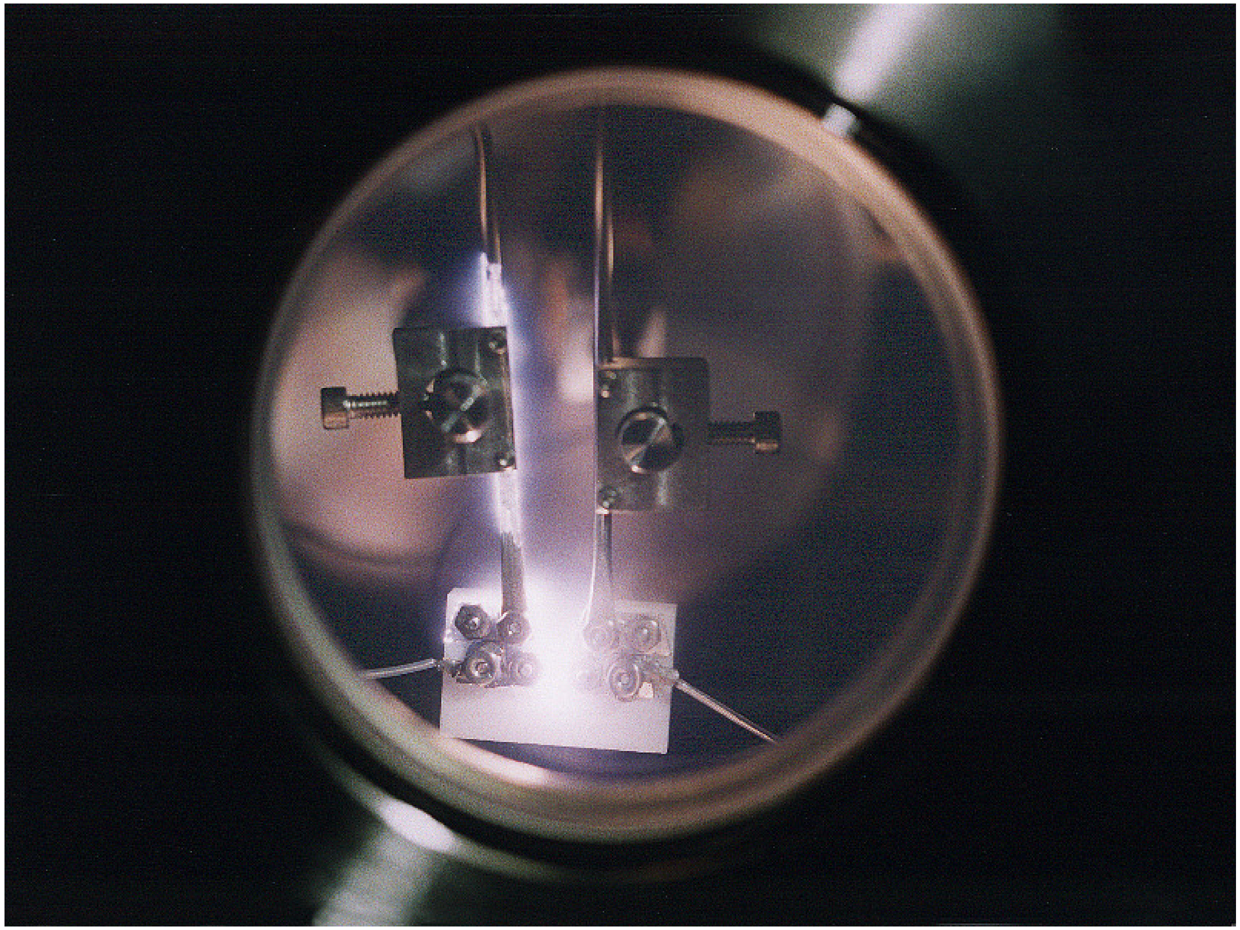
Oct. 26, 1998



- First demonstration of a sustained tin plasma, generated by a single Tin-Whisker

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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.

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