Understanding Tin Plasmas: A New Approach to Tin Whisker Plasma Risk Assessment

Dr. Maribeth Mason

Dr. Genghmun Eng

Microelectronics Technology Department

Electronics and Photonics Laboratory

The Aerospace Corporation

IEEE IRPS, U.Md. CALCE

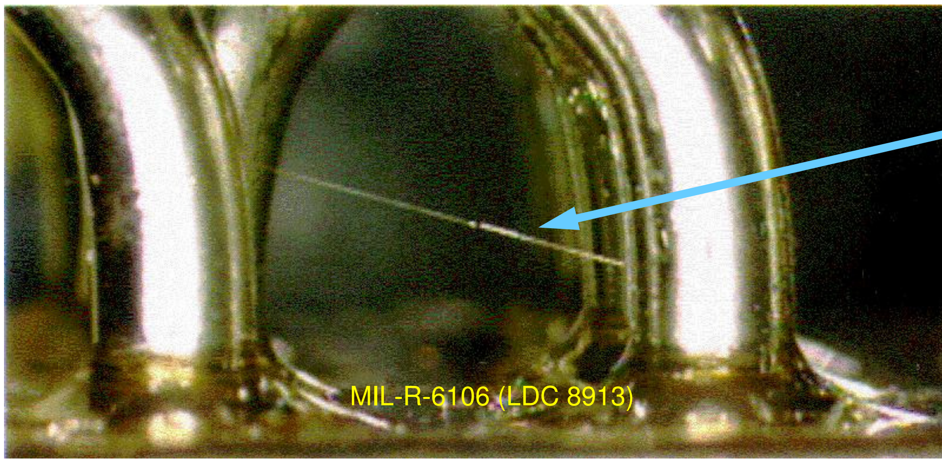
April 2007

THE AEROSPACE CORPORATION

Outline

1. Tin Whisker Plasmas: Introduction
2. Aerospace Tin Plasma Test Facility
3. Tin Plasmas in Vacuum
4. Tin Plasmas at 1 Atmosphere
5. Conclusions

Tin Whisker Electrical Shorts Can Develop Into Sustained Plasmas



Long tin whisker growing between pure tin-plated terminals in an electromagnetic relay.

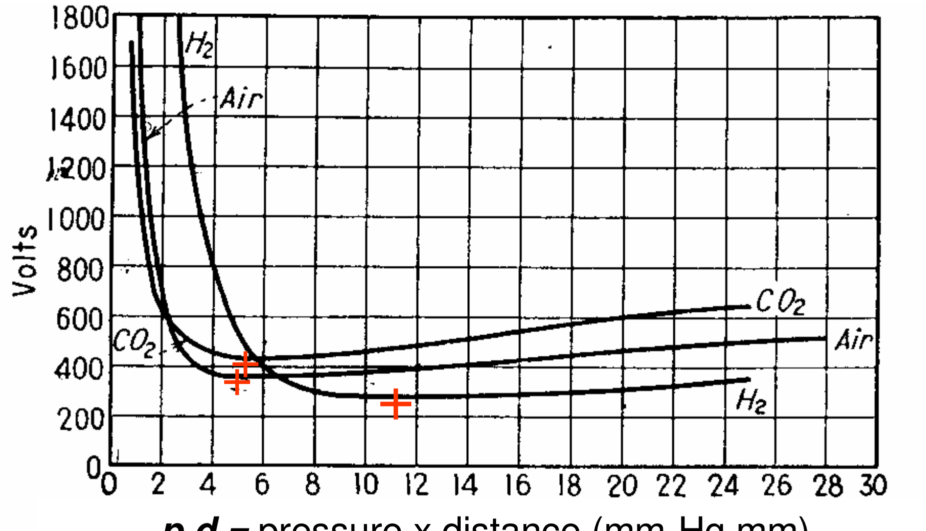
Photo Courtesy of the NASA Electronic Parts and Packaging (NEPP program) – http://nepp.nasa.gov/whisker

Known: Plasmas initiated by tin whiskers in a vacuum can carry tens to hundreds of amperes and blow spacecraft fuses.

Unknown: How does a plasma strike and sustain itself ?
How does it depend on voltage, pressure, distance, and other factors?

We seek a better scientific understanding of tin plasmas to better assess and mitigate tin whisker risk.

Paschen Curve Shows Minimum Voltage Below Which Plasmas Do Not Form



p d = pressure x distance (mm-Hg mm)

- Historical data give the Paschen curve for pure gases.
- The minimum voltage to form a tin plasma is unknown.
- The voltage required to strike a tin plasma may differ from the voltage required to sustain the plasma.

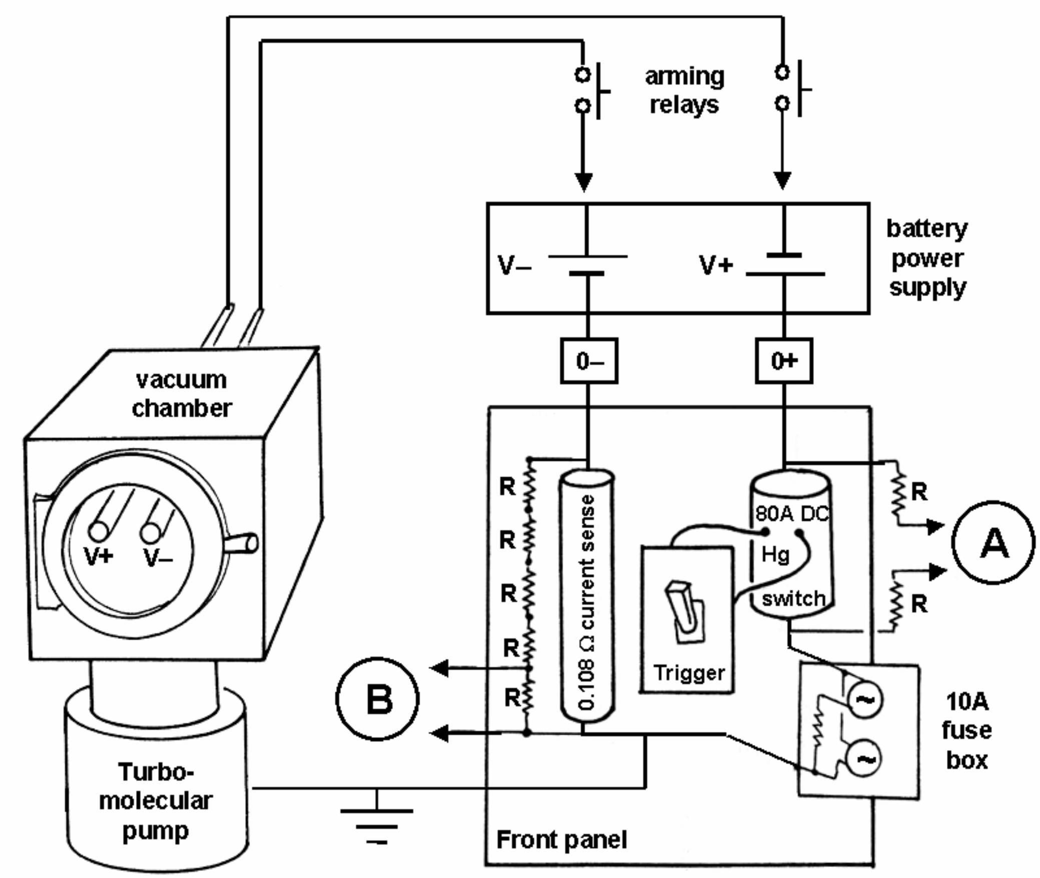
Figure: W. O. Schumann, *Elektrische Durchbruchfeldstarke von Gasen,* Springer-Verlag, Berlin, 1923.

Aerospace's Tin Plasma Test Facility

Vacuum chamber with high-power feedthroughs

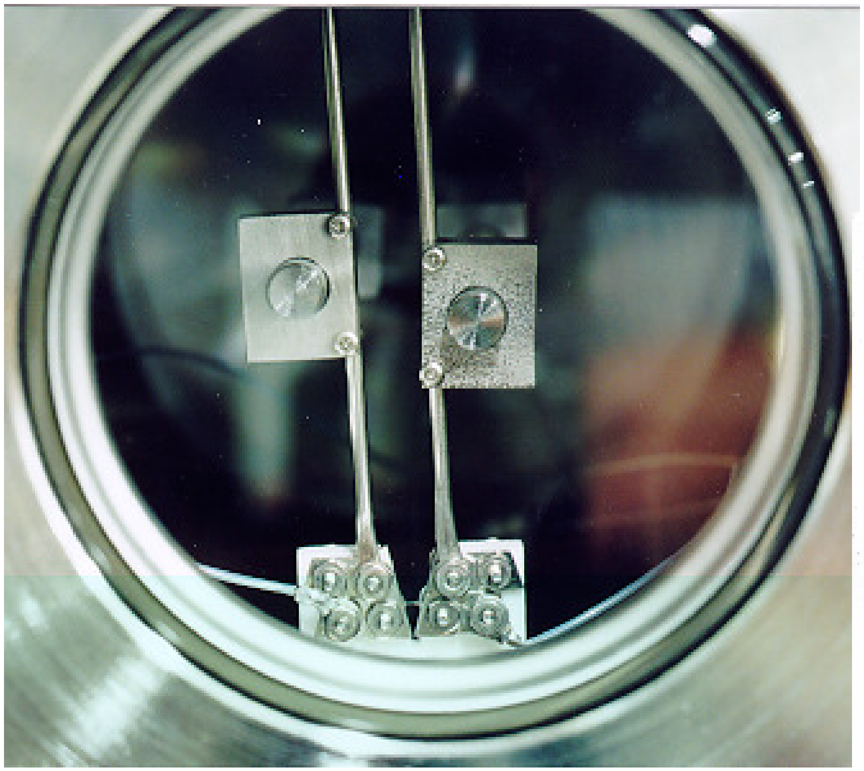
Lead-acid battery-based power supply with DC voltages selectable between 2 and 48 V

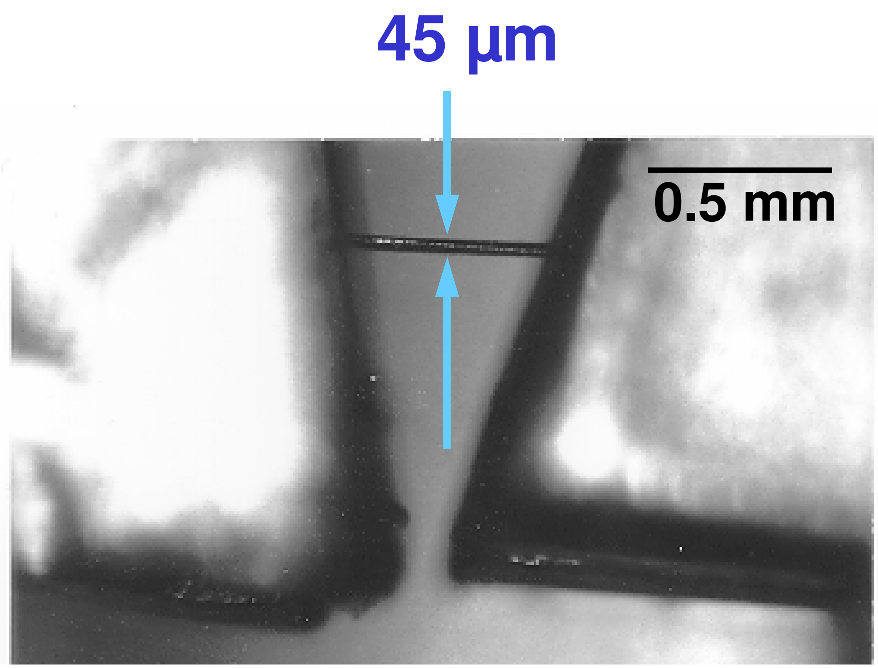
Fast-transient data capture system to record plasma voltage and current profiles



THE AEROSPACE CORPORATION

Aerospace's Tin Plasma Test Facility



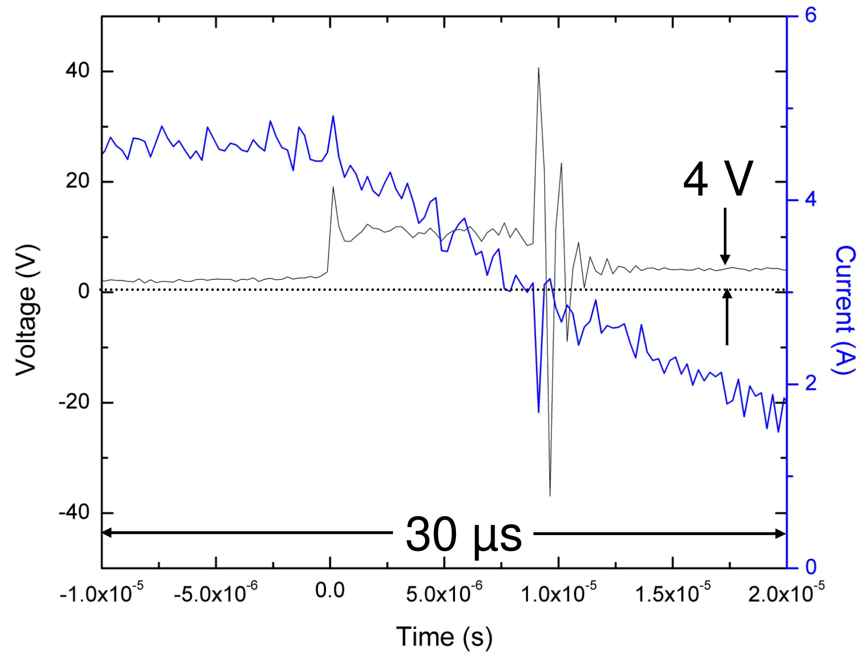


Thin tin wires 25-50 µm in diameter were substituted for 0.5-25 µm tin whiskers.

Tin-plated holder and Jacob's Ladder structure allows plasma to propagate

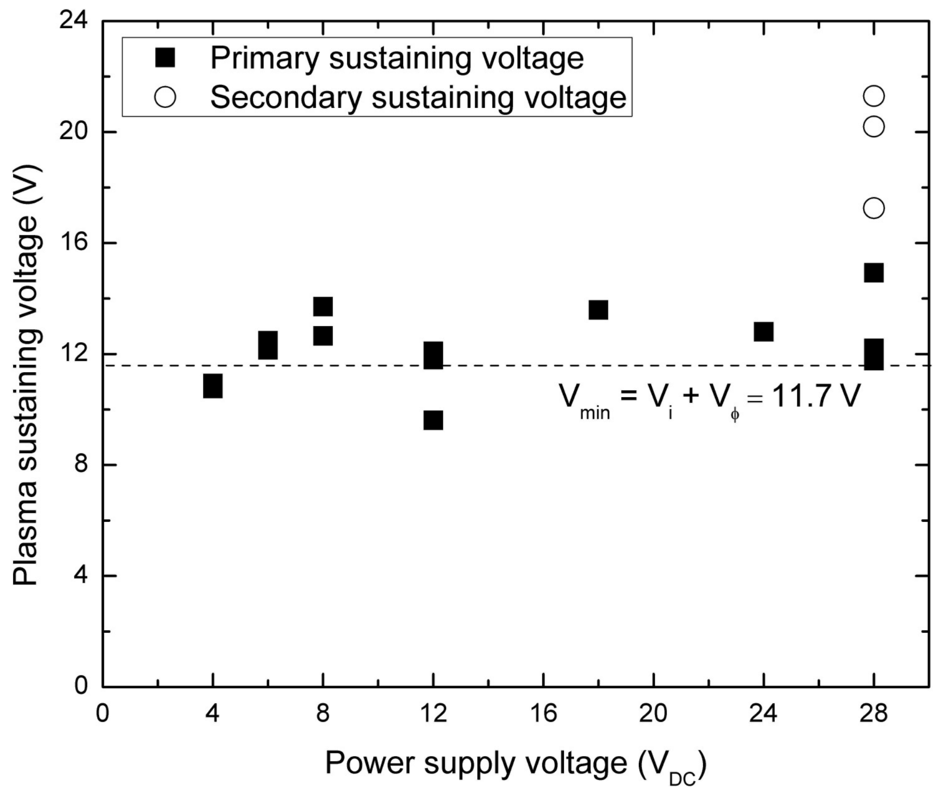
Low Voltage Tin Plasmas in Vacuum

- Sustained plasmas form at power supply voltages as low as 4 V
- Plasma strike due to a voltage transient that develops across wire break
  - Voltage exceeds power supply voltage
  - Transient is due to discontinuity in circuit capacitance
- Current remains continuous across the wire break



THE AEROSPACE CORPORATION

Minimum Plasma Sustaining Voltage



Minimum theoretical plasma sustaining voltage:

$$e\,V_{min} = U_{min}$$

$$= U_i + U_\varphi = eV_i + eV_\varphi$$

Ionization potential of tin vapor:

$$U_i = 7.3 \text{ eV}$$

Work function of tin-plated contacts:

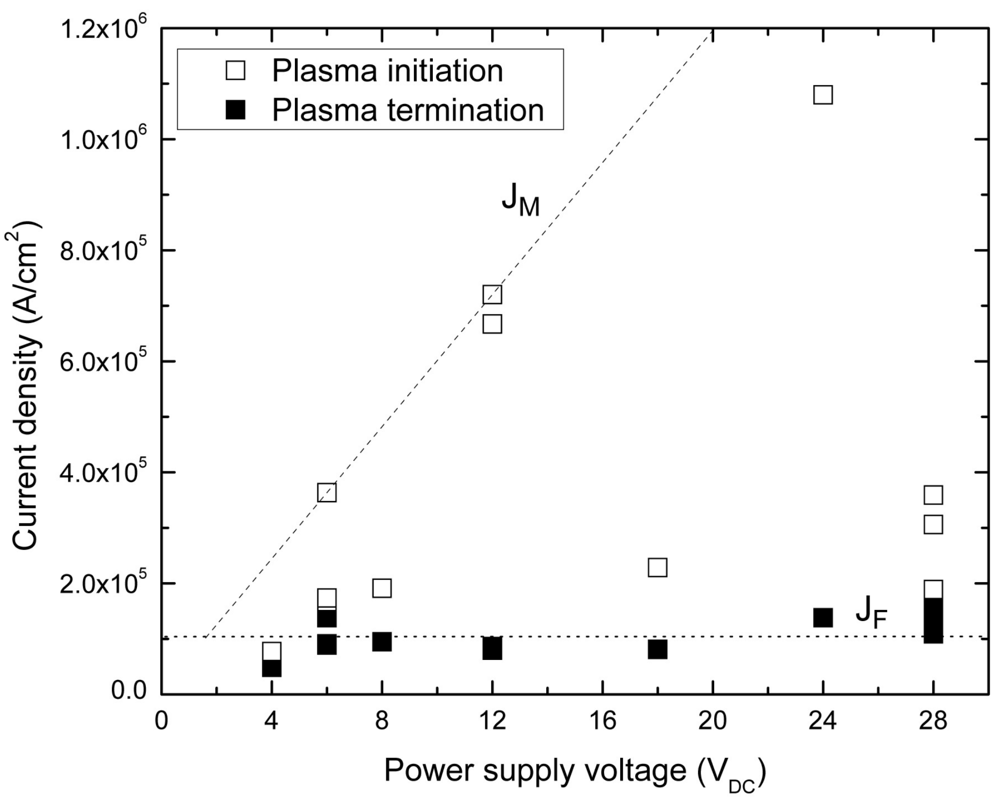
$$U_\varphi = 4.4 \text{ eV}$$

***V_{DC}* < *Vmin* or *V_{DC}* near *Vmin* :** plasma stabilizes near *Vmin* independent of V_{DC}

***V_{DC}* >> *V_{min}* :** second stable voltage plateau may exist

Tin Plasma Current Density

Current density at initiation J_M increases with V_{DC}
Current density at termination J_F is independent of V_{DC}



$J_M / J_F = V_{DC} / V_L$

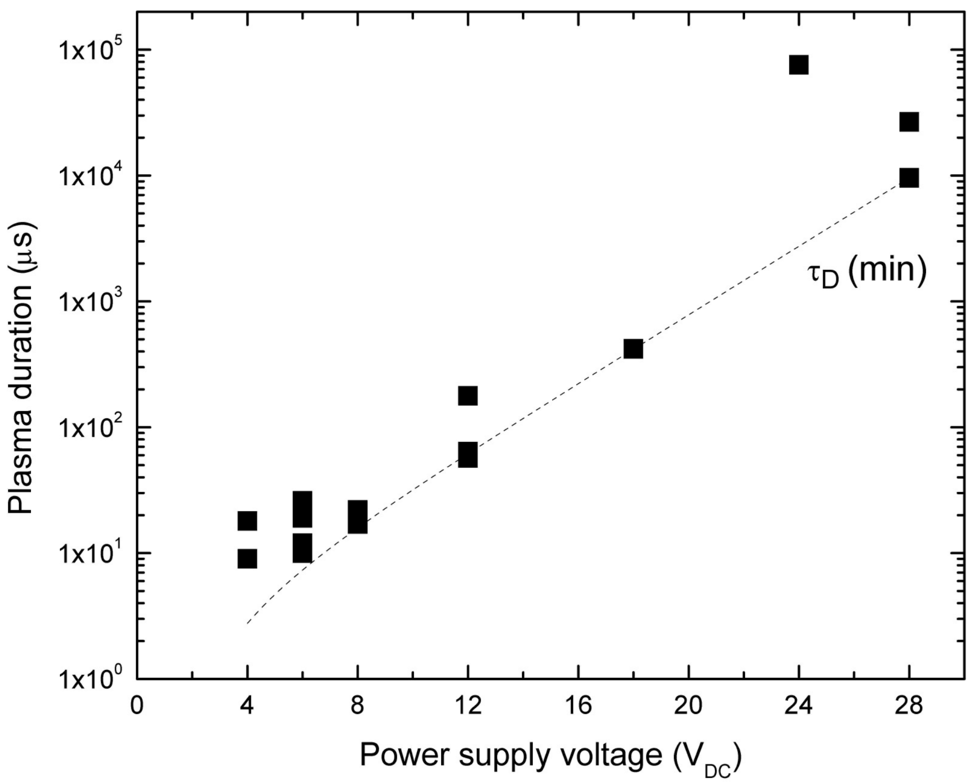
$J_F = 1.04 \times 10^5$ A/cm^2

V_L = 1.6 V is a fitting parameter

V_L may be interpreted as a minimum voltage below which a tin plasma may not exist.

THE AEROSPACE CORPORATION

Tin Plasma Duration



Plasma continues until minimum arc current density is reached.

At higher power supply voltages:

- Plasma duration increases.
- Initial plasma current density increases.

Lower bound for plasma duration:

$$\tau_D \geq \tau_M \{exp[+V_{DC}/V_C] - exp[+V_L/V_C] \}$$

$$\tau_M = 1.5\ \mu s$$

$$Vc = 3.2\ V$$

Implications for Future Space Programs

Minimum DC voltage for sustained plasma < 4 V

- *Voltage < 5.5 V DC for transistor and logic circuits*

Voltage spikes at initial wire break and end of plasma exceed DC power supply voltage.

- *Increased impact if circuits are sensitive to transients*

Engineering estimates for tin whisker risk vs. power supply voltage have been developed.

Facility is available to help assess specific risks.

Helping Evaluate NASA Space Shuttle Risks

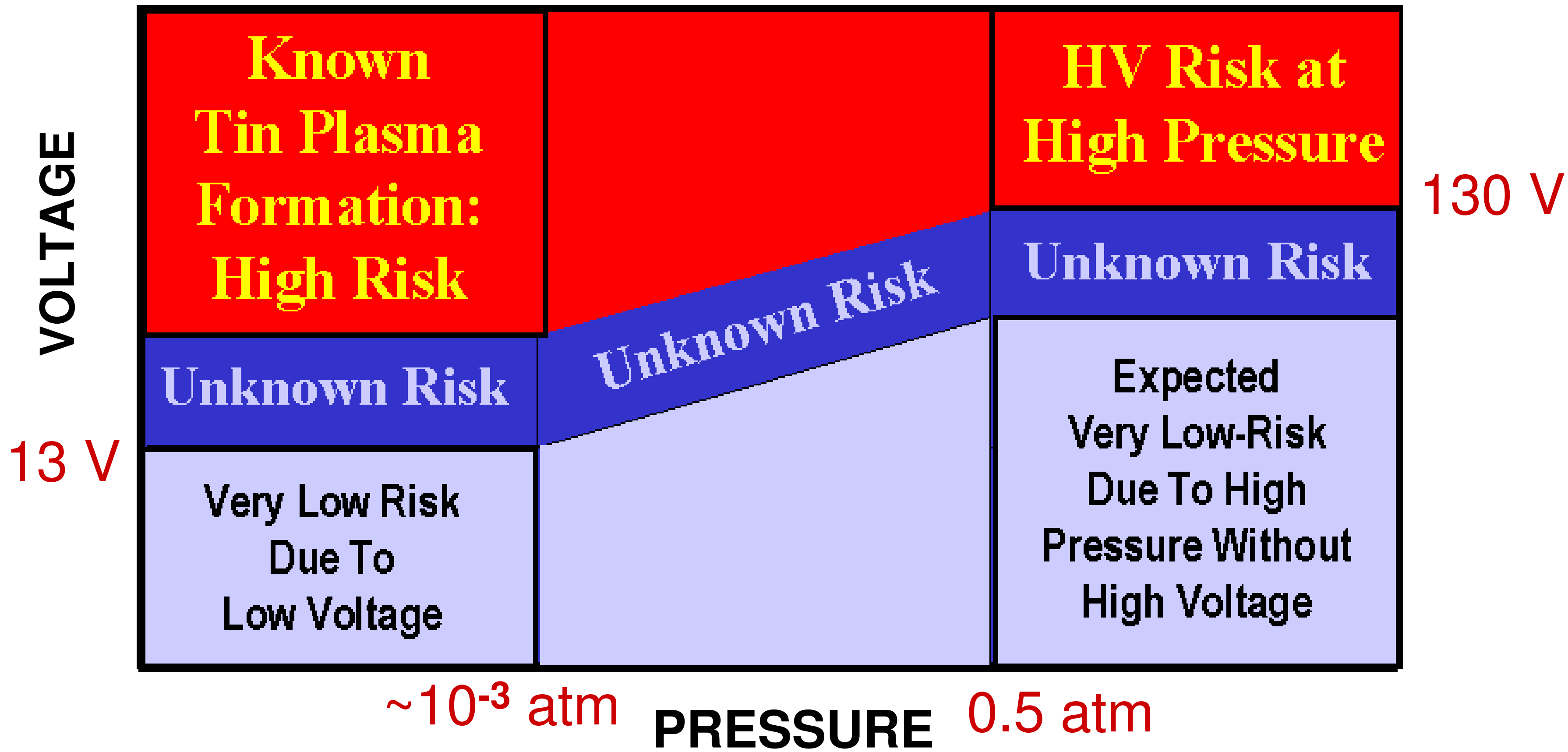
Before the STS-121 Shuttle mission launch, NASA discovered “forests” of 10,000+ tin whiskers in the avionics hardware.

Initial NASA analysis indicated extremely low risk.

Aerospace Test Facility was able to experimentally test NASA assumptions in a timely manner.

THE AEROSPACE CORPORATION

NASA Analysis Summary



Space Shuttle avionics operate at 28 V and 1 atm.

- NASA analysis had numerical values only for the Very Low Risk (<13V) and Known High Risk (>130V, >0.5 atm) Regimes.
- NASA extrapolation of the Very Low Risk Regime to higher pressure put Shuttle avionics in an Expected Very Low Risk Regime.

THE AEROSPACE CORPORATION

Gas Environment Factors That Can Affect Tin Plasma Formation at 1 atm

1. N_2 is more difficult to ionize than O_2
   $\Rightarrow$ Tin plasmas might be more likely to form in air

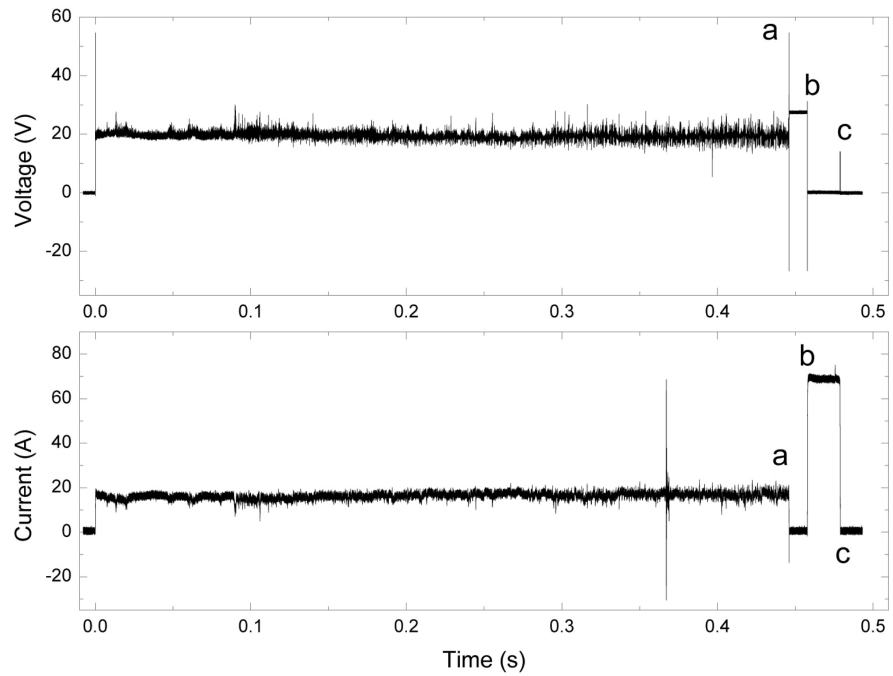
2. N_2 is almost inert, while O_2 might enable protective surface oxides to form
   $\Rightarrow$ Tin plasmas might be more likely to form in nitrogen

Which model dominates tin plasma formation at 1 atm?

Tin Plasma at 28 V in 1 atm N_2

Plasma Event

Tin Plasma at 28 V in 1 atm N_2



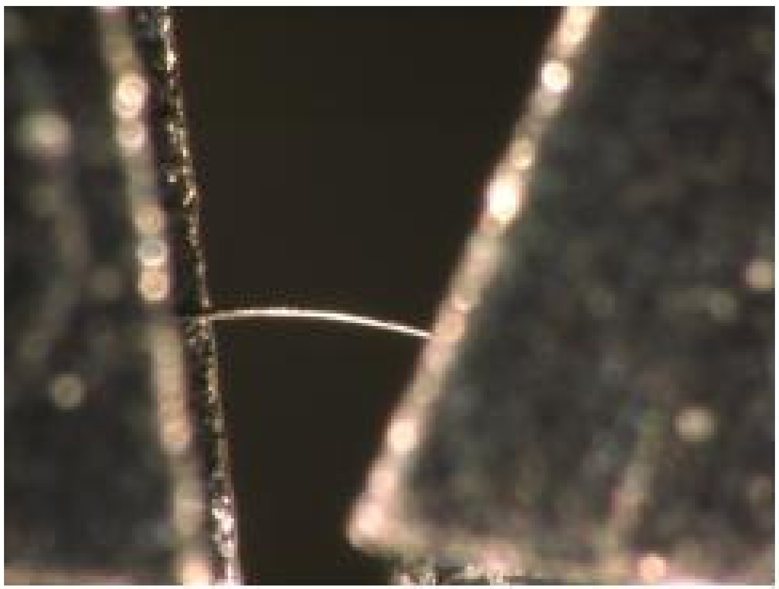
(a) Plasma blew 10 A fuse 450 ms after initiation

(b) Tin reflow formed short circuit path

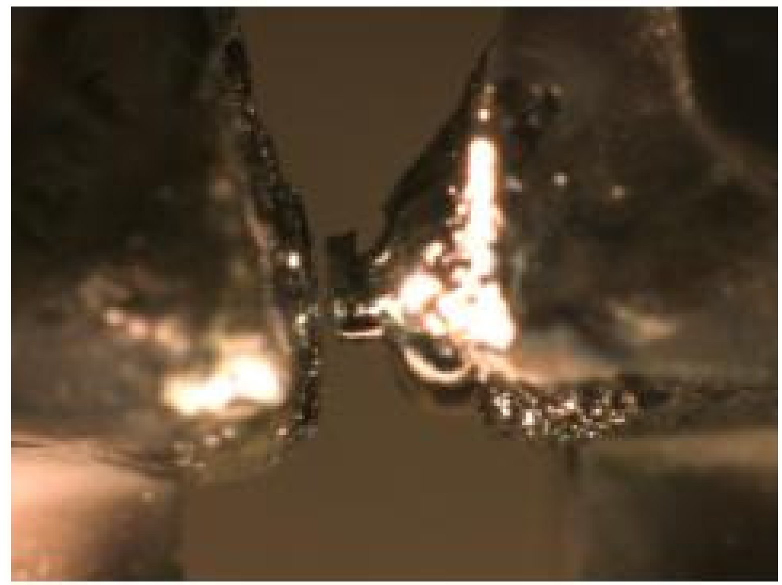
(c) System power manually shut off

Tin Plasma at 28 V in 1 atm N_2

Test fixture before test



Test fixture after test



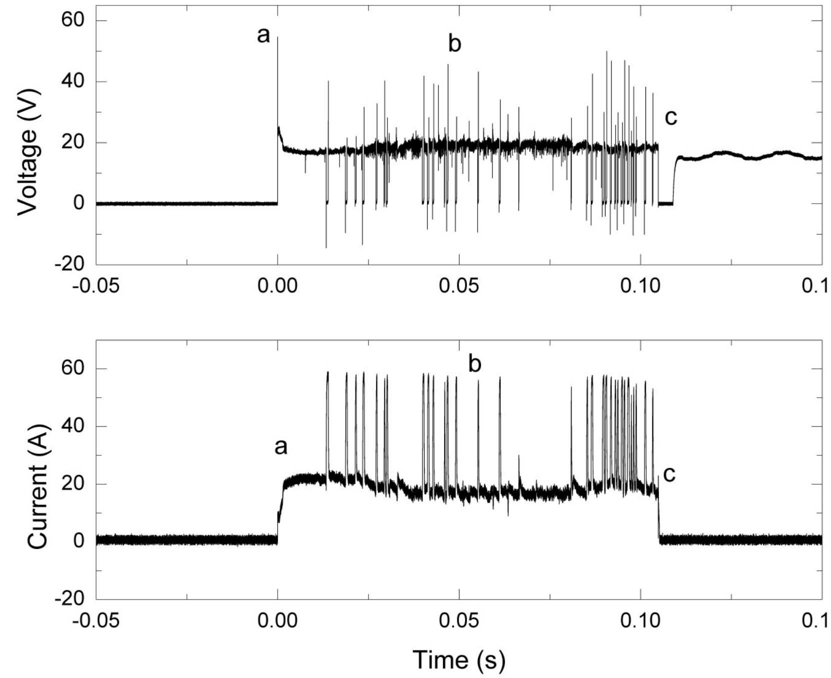
Tin Plasma at 28 V in 1 atm Air

TinPlasmaAir-short.avi

Plasma Event

THE AEROSPACE CORPORATION

Tin Plasma at 28 V in 1 atm Air



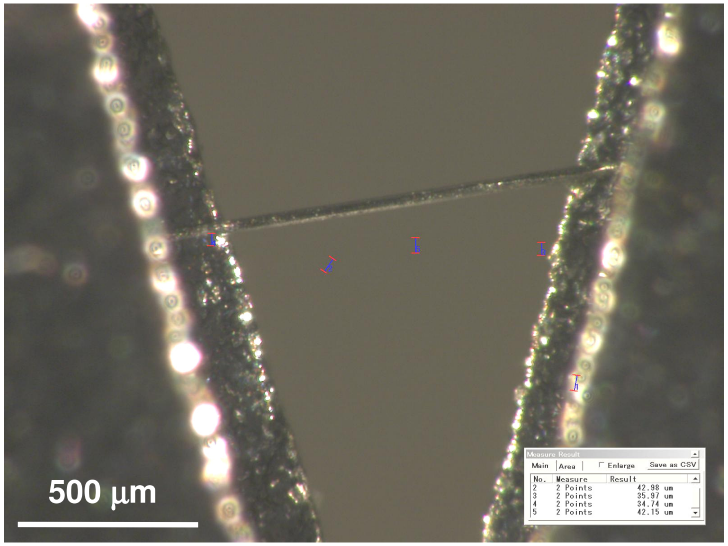
(a) Plasma initiation

(b) Tin reflow reformed connections (31 times!) carrying ~56 A current

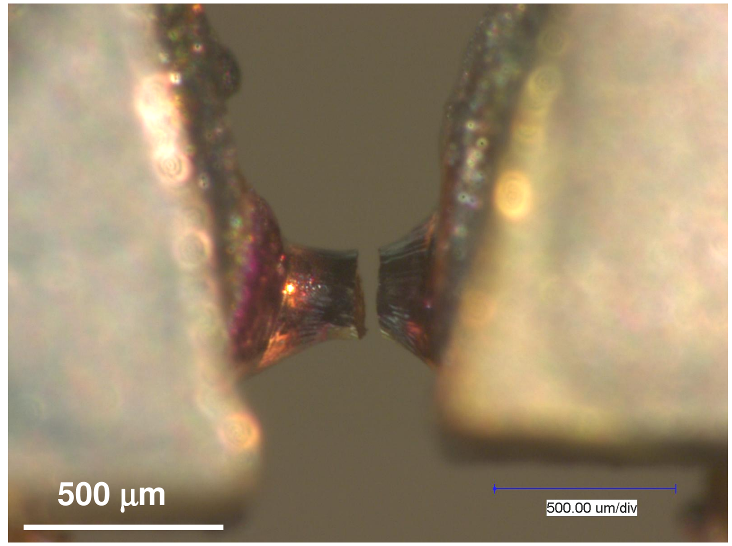
(c) Plasma blew 10 A fuse 105 ms after initiation

Tin Plasma at 28 V in 1 atm Air

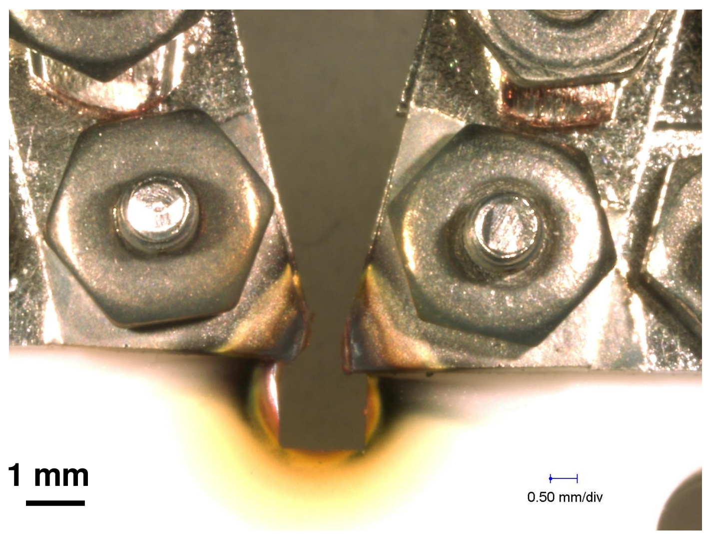
Test fixture before test



Test fixture after test



Plasma caused the destruction of tin and underlying copper; damage to ceramic fixture



Plasmas in Air vs. Plasmas in N_2

	Air	**N_2**
Average plasma current	18 A	17 A
Tin plating reflow	More reflow	Less reflow
Short circuits created by reflow	Fully vaporized during plasma	Fractured metal bridge remained

Oxygen ions and radicals attack electrodes faster than any tin protective oxide can form ⇒ more tin from electrodes can vaporize with oxygen present.

Plasmas in air are more pernicious than plasmas in N_2.

Conclusions for Tin-Plasmas at 1 atm.

- The risk of using tin whisker-containing components in 1 atm of air with a 28 V power bus is comparable to, or possibly worse than the already known high risk for tin-plasma formation in a vacuum.

- Tin plasma formation at 28 V and 1 atmosphere of air may be more destructive than tin plasma formation in N_2 or vacuum, because oxygen ions and radicals can form, helping to sustain the plasma.