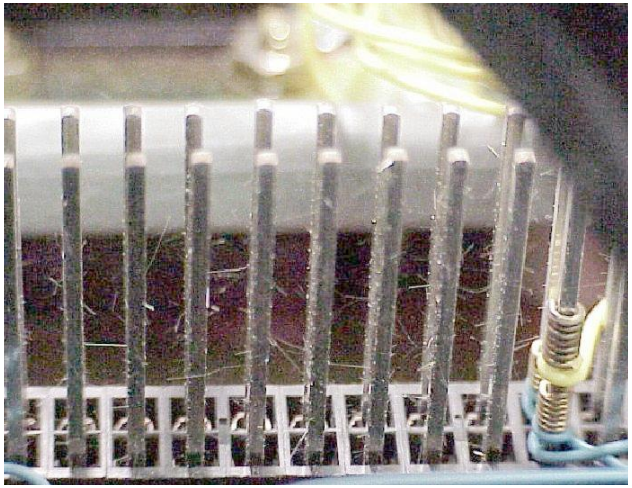
MITIGATING AND PREVENTING THE GROWTH OF TIN AND OTHER METAL WHISKERS ON CRITICAL HARDWARE

Stephanie Barr
The Aerospace Corporation
2525 Bay Area Blvd Ste 600
Houston, TX 77058
281-283-6416
Stephanie.e.barr@aero.org

Mitigating and Preventing the Growth of Tin and Other Metal Whiskers on Critical Hardware

What are Tin (and other Metal) Whiskers?

- Thin protrusions, like hairs, that grow out from a metal plated surface.
- ~1-10 μm in diameter, they can grow several mm long, though they are generally shorter than 1 mm.
- No one has definitively proven what causes metal whiskers or what speeds or retards their growth.
- Other metals prone to whiskers include zinc and cadmium as well as silver (though that is linked with a sulphur environment).

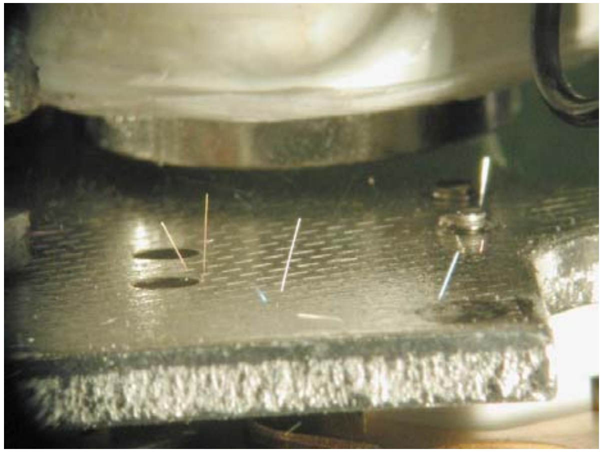


Tin whiskers growing from pure tin plated connector pins after ~10 years. Courtesy of GE Power Management

- Tin whiskers can be prevented by including >3% lead to the tin alloy.
- Metal whiskers are not a new phenomena, but new restrictions precluding the use of lead for electronics have made pure tin plating more prevalent
- This increased use of pure tin plating is a concern for high reliability electronics, such as medical usage, nuclear power plants, and aircraft and space applications.
- Zinc whiskers growing on galvanized steel plated computer floor panels have also been a concern for large computer complexes.

Mitigating and Preventing the Growth of Tin and Other Metal Whiskers on Critical Hardware

Problems Metal Whiskers Can Cause



Tin whiskers growing in a hermetically sealed relay that was pure tin plated.

Courtesy of Northrup Grumman

- Transient short by tin whisker where a current (generally <50 mA) fuses the whisker almost immediately. Although it is short lived, sensitive components could be adversely affected by the short term short.
- Sustained short where insufficient current exists to melt the whisker. These kinds of shorts, common for data or control circuitry, can provide erroneous readings, initiate unwanted commands or prohibit desirable commands. They may also be difficult to prevent, detect or mitigate.
- A metal vapor arc can be created higher power circuits. In this case, the vaporized metal ions become a conductive path for the arc between contact surfaces of different potential. This is a highly destructive phenomena and will be addressed separately (see next page).
- Attached whiskers can become antenna at frequencies above 6 GHz, disrupting digital circuits.
- Even detached whiskers can drift (or be propelled by air handling systems) into connected areas and affect circuitry in a different physical location.

THE AEROSPACE CORPORATION

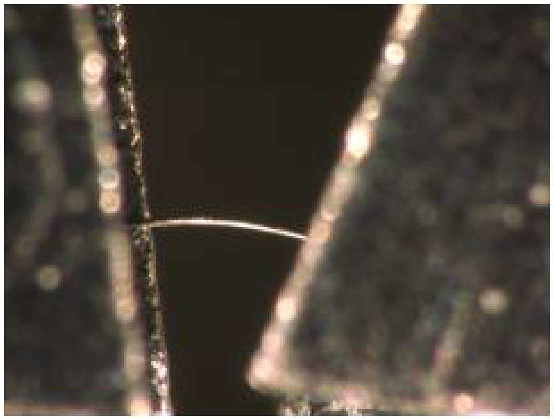
Mitigating and Preventing the Growth of Tin and Other Metal Whiskers on Critical Hardware

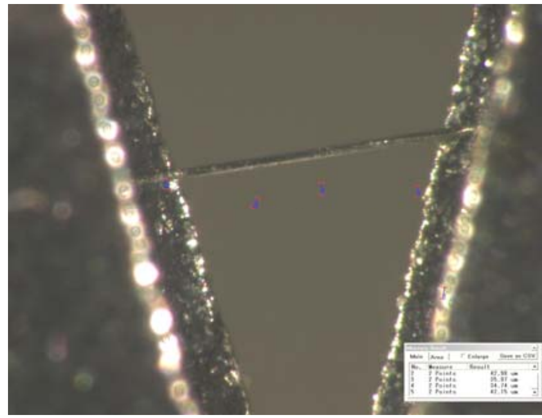
Metal Vapor Arcing (MVA) – Transient and sustained shorts can be predicted and protected for easily. The thresholds and conditions that will allow for metal vapor arcing are not as clear, nor is remediation simple.

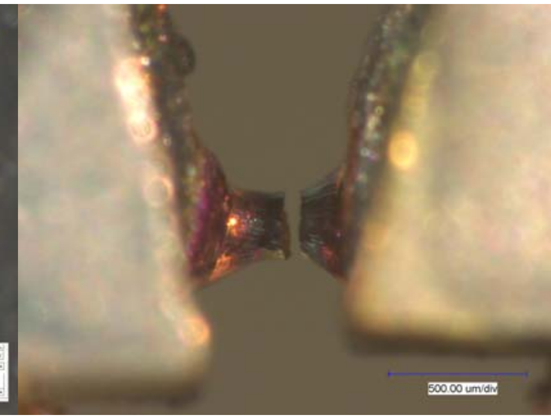
- When a metal vapor arc (MVA) occurs, the impact on equipment is considerable, not only from the high current flowing through the arc, often tens to hundreds of amps, but also from the extreme heat as the MVA vaporizes more metal from the contacts to feed itself.
- Sustained MVA has been documented in vacuum tests at voltages as low 4 VDC. In both air and nitrogen at atmospheric pressures, sustained MVA has been demonstrated at 28 VDC, with highly destructive results, as shown in the pictures and videos on the following pages. These tests pulled up to 70 A through the arc.
- Repeated reflow and extensive destruction taking place in fractions of a second can have profound implications for sensitive circuitry, flammable environments, and functional reliability. In the nitrogen test, for instance, a 10 A slow-blow fuse blew but reflowed, pulling ~70 A. The arc was maintained for more than a second and had to be shut off manually. Actuation of the control circuitry itself may disable a system or a level of redundancy.
- With susceptibility at atmospheric pressures, MVA could be a concern not only for space circuitry at vacuum, but also circuitry in habitable volumes and even for ground support systems critical to space safety.
- **If MVA is not recognized as a potential hazard, control circuitry may be insufficient to preclude critical results. Possible component and physical heat damage, as well as potential ignition, are catastrophic hazards for space.**

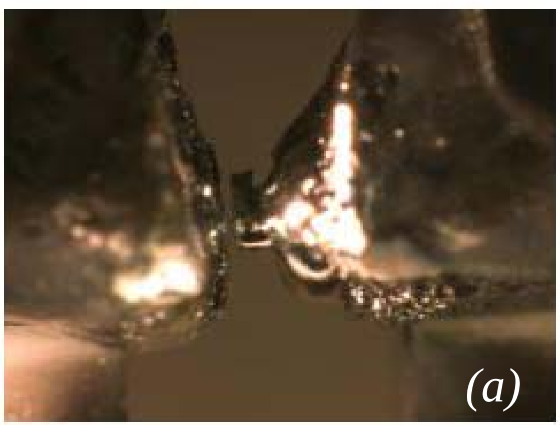
Mitigating and Preventing the Growth of Tin and Other Metal Whiskers on Critical Hardware

Metal Vapor Arcing – Example Test Results

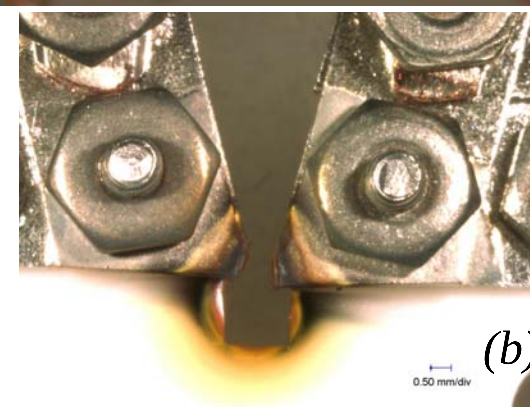








Before and after pictures of (a) the nitrogen MVA test and (b) the air MVA test, courtesy of The Aerospace Corporation Microelectronics Technology Dept.



Mitigating and Preventing the Growth of Tin and Other Metal Whiskers on Critical Hardware

Metal Vapor Arcing – Test video of Nitrogen MVA Test

Mitigating and Preventing the Growth of Tin and Other Metal Whiskers on Critical Hardware

Tin whiskers have already caused considerable damage. Here is a partial list of some significant failures from metal whiskers (see http://nepp.nasa.gov/whisker/ for more).

- Nuclear reactor shutdown as a result of tin whiskers on tin plated relays.
- Tin whiskers on tin plated relays caused or contributed to the complete loss four commercial satellites and the redundant systems of three more.

Relay destroyed by a metal vapor arcing event. Courtesy of Northrup Grumman

- Pacemakers were recalled for failures related to tin whiskers.
- Detached zinc whiskers have been identified as the cause for power supply failures (often repeated failures) in several significant data handling facilities.
- Several spectacular relay failures in aircraft were linked to tin whiskers growing on a tin plated surface. These metal vapor arcing events caused considerable damage (see above).
- A metal vapor arcing event between a plated bus rail and a chassis in a ground thermal vacuum test, lasted 4.7 s before blowing 11 pairs of 20 A fuses, melted the bus bar and part of the chassis.

THE AEROSPACE CORPORATION

Mitigating and Preventing the Growth of Tin and Other Metal Whiskers on Critical Hardware

The most effective method to prevent metal whisker hazards is to avoid the use of susceptible plating materials like pure tin or electroplated zinc. Adding lead (>3%) to tin solder has been shown effective in preventing whiskers.

- History shows that a requirement or specification prohibiting the use of such finishes as pure tin is not enough to preclude use.
- For critical applications, independent/objective verification that whisker-prone plating materials are not in use may be required.
- Because of RoHS and other environmental regulations, finding parts that are not prone to whiskering (such as those with lead alloy solders) may be increasingly difficult.

Mitigating and Preventing the Growth of Tin and Other Metal Whiskers on Critical Hardware

Tin whiskers on Tin-Plated Kovar Terminal having a Nickel Barrier Plating. Whiskers formed on region that was NOT encompassed by the Tin-Lead (Sn-Pb) solder applied during hot solder dip operation. Courtesy of NASA Electronic Parts and Packaging (NEPP) Program *http://nepp.nasa.gov/whisker*

Mitigation methods and their limitations.

- Manufacturing
  - Nickel underlay or adding silver or bismuth to solder, which may not be usable for all applications.
  - Hot dipping, reflowing, etc. can reduce whiskering but may be impractical for finished hardware (see photo).
  - Various other manufacturing methods, many of which are promising but have not been proven.
- Post-manufacturing (available for end user)
- Conformal coating, which is believed to slow whisker growth, but may reduce dormancy period. Conformal coating does not stop whiskers from growing through. It may provide some protection from MVA by limiting source metal.
- One can design sufficient gaps in critical circuits to preclude tin whisker shorts, but, with whiskers potentially longer than 10 mm, this can be very limiting.
- Control circuitry <u>may</u> limit the effects of tin whiskers if all possible failures are well understood.

THE AEROSPACE CORPORATION

Mitigating and Preventing the Growth of Tin and Other Metal Whiskers on Critical Hardware

Conclusion.

- **The most effective mitigation for metal whiskers is not using susceptible plating materials in, accessible to, or interacting with critical circuitry. Tin combined with >3% lead has been effective in preventing tin whiskers.**
- **Prohibiting susceptible plating may not be enough to preclude use. Requirements do not provide objective evidence of compliance. Testing is recommended for critical components.**
- In those areas where susceptible plating cannot be precluded, other steps can be used to address the repercussions of metal whiskers (conformal coating, geometry, circuit design, control circuitry), but the limitations of these mitigations must be clearly understood. For critical applications, a combination of mitigations may be necessary.
- Metal vapor arcing is a serious issue that can affect high power circuits very destructively. Susceptibility to MVA should be evaluated, optimally, by test where whiskering cannot be precluded and controls put in place that do not disable systems and provide sufficient response time to preclude critical damage.