Preventing Tin Whisker Growth Risk

Bob Landman, Gordon Davy, Dennis Fritz
LDF Coatings, LLC
Tin Whisker Facts

1. Despite much effort, no one has yet developed an electroplated Pb-free tin finish that can be confidently regarded as having a negligible risk that whiskers will grow long enough to cause a short circuit.

2. There is a growing suspicion that such a recipe may be as elusive as the philosopher's stone.
3. Even if a recipe to produce a tin-plated finish with a negligible whisker growth risk (WGR) were to be developed, before it could benefit manufacturers of high-reliability electronic systems, the vast majority of electronic component manufacturers would have to adopt it.
Tin Whisker Facts

4. For that adoption to happen, the recipe would have to entail negligible additional complexity and cost over present practices, since component manufacturers have not discerned a demand for it from their primary market.
Tin Whisker Facts

5. Even if a recipe to produce an inexpensive tin-plated finish with a negligible WGR were to be universally adopted by component manufacturers, despite much effort no one has yet even proposed a test method that, for a given batch of purchased components, could confirm that the manufacturer had without error followed the recipe.

6. There is a growing suspicion that such a test method may also be as elusive as the philosopher's stone.
Tin Whisker Facts

7. Even if a test method to confirm that a given tin finish had a negligible WGR were to be developed, it would necessarily be more complex and time-consuming than X-ray fluorescence, and hence, with few if any exceptions, impractical to use for screening purchased components.
Tin Whisker Facts

8. In addition to the unavoidable WGR associated with the use of commercial components, there is an unavoidable WGR associated with the use of COTS assemblies, which may also incorporate a Pb-free tin-rich solder (e.g., SAC) and a Pb-free tin-rich board finish (e.g., immersion tin).
Tin Whisker Facts – Summary

Despite the best efforts of all the king's horses and all the king's men, until the prohibition on the use of Pb in electronics is lifted, electronic assemblies that incorporate Pb-free tin will continue to pose a significant WGR (i.e., forever).
WGR Remedy Deficiencies

1. Even where a tin-lead termination finish is available for a desired component, its procurement often entails a significantly higher price and a significant delay.
WGR Remedy Deficiencies

2. Replacing tin with tin-lead (i.e., by dipping or replating) is expensive; also, dipping component terminations in molten solder introduces other risks – heat and handling damage that result in latent failure modes that escape detection.
WGR Remedy Deficiencies

3. Depending on finish replacement during soldering (i.e., based on termination shape and size) at best can only apply to a subset of all components used on an assembly.
WGR Remedy Deficiencies

4. Scrubbing a bill of material to identify each component that has a significant WGR is expensive and subject to mistakes.
WGR Remedy Deficiencies

5. Screening lots of received components to catch those with Pb-free tin plating (wrongly ordered or wrongly shipped) is expensive and subject to mistakes.
WGR Remedy Deficiencies

6. For COTS assemblies, the above means are not just impractical. They are impossible.
WGR Remedy Deficiencies

7. Because some whiskers soon penetrate the most widely used conformal coatings, these coatings at best only reduce (mitigate) WGR.
WGR Remedy Deficiencies

8. Commercial conformal coating application processes result in regions with inadequate coverage (too thin or missing entirely).
WGR Remedy Deficiencies

9. No one has yet developed a practical screening method to reveal regions with inadequate conformal coating coverage, which may be quite small but quite numerous.
WGR Remedy Deficiencies

10. Even with a process/material combination that ensures adequate coverage everywhere, even the best conformal coating, being a polymer, has relevant physical properties (in particular, adhesion and penetrability) that vary significantly within the service environment and lifetime.
WGR Remedy Deficiencies

11. No one has yet demonstrated how effectively any polymer coating would reduce WGR over the full range of temperature (-55° to +125° C) and humidity (0 to 100%), for the full intended service life (30 years) of a high-reliability electronic system.
Hazards of Ignoring WGR

1. Moral – if ignoring the risk is knowing and deliberate:
Counting on the customer's difficulty proving that a whisker was the cause of a given malfunction.
Hazards of Ignoring WGR

2. Whether knowingly or unknowingly (i.e., whether the neglect is deliberate or tacit):
A field failure rate too large to conceal the cause from the customer.

- If this occurs, it entails huge costs and delays.
- In seeking a remedy, the manufacturer must in many cases engage outside expertise.
- Frequency of occurrence is unknown because victims conceal most cases.
- Victims’ failure to reveal → more victims (i.e., due to managers’ unawareness of, or underestimating the magnitude of, the risk).
Acceptance Requirements for Any Remedy

It shall be:

1. Safe
   - “First, do no harm” (Hippocrates, 4th cent. B.C.)

2. Effective
   - “A little dab’ll do ya” (Brylcreem)

3. Practical
   - “Best thing since sliced bread”
The TW *Prevention* Challenge

Find a TW *prevention* means more practical than component termination finish replacement

– Applicable to a soldered assembly
– Able to protect from TW shorts *permanently*
– Must *cap* Sn with a TW-impenetrable material
– How about a *non*-capping process to overcome Pb-free Sn’s TW proclivity? 😞
Three Possible Capping Means

- Ceramic
  - Applied layer-by-layer in a vacuum system
  - 200 nm cap unpenetrated > 1 yr.

- Polymer
  - Thixotropic for complete coverage
  - Resilient rather than impenetrable
  - Substitute for conformal coating

- Metal
  - Deposited \textit{selectively} on Sn and other metals

1. TW \textit{tents} the cap
2. Cap \textit{buckles} the TW
Acceptance Requirements for TW Capping Process/Product

It shall be:

1. Safe
   - Capping process shall not harm the assembly
   - Cap’s impenetrability shall survive temp cycling, RH, and time
   - Process and cap material shall be safe for people

2. Effective
   - Process shall give consistent results within wide margins
   - Cap shall *prevent*, not *retard*, TW penetration
   - Cap’s TW *prevention* shall be permanent

3. Practical
   - Process shall be quick, easy, inexpensive, and integrate well into assembly/test process flow

Still a long way from an acceptance test specification
Next Steps to a Cap Process
Acceptance Test Specification

1. Test or analyze?
   • If test,
     • What kind of tests are appropriate for this type of cap?
     • Test severity and duration?
   • If analysis, what are the analyst’s qualifications?

2. What does it take to pass the test?
   • How confident can you be that passing each test = meeting the corresponding requirement?
   • What is the baseline?
   • Who decides?
Perspective on **Proving** vs. **Convincing** – of *Prevention Means’ Effectiveness*

*TW mitigation means* now in use are *marginal*

- this *mitigates* the need for **proof**
  - Do you *really* need to wait for 30 years to show no TWs?
  - Where’s the **proof** that your TW *mitigation means* is adequate?

**Baseline** –
Is this *prevention means better* than what we’re doing now?

Prevention \(\Rightarrow\) Mitigation

*Prevention* replaces, not augments, *mitigation*
New topic – Process

Req’s for **Ideal** TW Prevention Capping Process

Apply process to *assembly*, not *components*

- **No Mitigation**
  - BOM scrubbing
  - Receiving inspection for Pb-free Sn
  - Auditing *mitigation* activity for compliance/effectiveness
- Cap and process are *safe* for product and people
- Cap and process are *effective*
  - *Permanently* suppresses TW growth
  - *Prevents*, not *mitigates*, TW risk for *all* assy’s, incl. COTS
  - *Must* settle for supporting data and rigorous analysis
- Cap process is *practical*
  - Fast
  - Low cost of ownership and labor
  - Non-sole source
  - Integrates easily into existing product flow
How can you metal-cap the Sn and *not* the assembly’s insulating surfaces?

- Metal cap process *must be selective*
- Vapor deposition – no way!
- You gotta give your baby a *bath!*
- Does it get wet after soldering?
- Wet with *what*?
- Wet’s wrong with *that*?
Selective Metal Cap Layer Process
For Coating Sn on Assemblies

Three options could be considered, but only one is OK

1. Electrochemical (electroplated)
   - All Sn surfaces must be electrically connected

2. Immersion (replacement)
   - Too thin

3. Electroless (autocatalytic) fills the bill
   - Surface preparation and rinsing are routine
   - Deposition is Yes or No, Go or No-Go
     - Go on Sn (and on most metals)
     - No-Go (not verrry slooow!) on all insulators →
   - Ni and Pd among TW-impenetrable metals
   - Mask just once
     - Surfaces not to be capped = surfaces not to be conformally coated

slow go
No go
Reactions

• Are you crazy? I’d never put any assembly of mine in a plating bath!!!
  – Why not?
  – You do remove flux by aqueous cleaning, right?
  – Are you “data-driven” or “intuition-driven”?

• But, but – that’s never been done before!!!
  – And your point?

• Will all the Sn plate?
  – Electroless plating a long-established industry practice
  – Sn’s native oxide coating only 2-3 nm, easily dissolved
  – It’s chemistry, not magic
  – If it’s Sn and it’s clean, why wouldn’t it?
New topic – Practical?

How does this all work?

• Flow diagram shows added and eliminated steps
• Scale layout drawing for each tank
TW *Mitigation* vs. *Prevention* Capping

**Conventional Process – TW *Mitigation*, not *Prevention***

**Process Differences in Color**

**New TW-*Prevention* Metal-Capping Process**
Ceramic- and polymer-capping processes similar
Electroless Plating System Layout Scale Model

Top View

Alkaline clean  Rinse  Acidic clean  Rinse  Electroless deposition  Cascade rinse  Dry station

Side View

10 in. (typ)  To drain  Water in  To drain  Water in  To drain  Water in

10 in.  14 in.
Proof of Concept – April 2010

1. **Effective**: Has Ni capped the Sn?
   Yes. First evidences: micro-bubbles, then altered appearance on Cu
   **Thickness**: 5-min. electroless deposition **XRF**: \( 2.9 \pm 0.2 \, \mu\text{m} \) Ni,
   2 assemblies, 3 locations ea.

2. **Effective**: Have TWs penetrated?
   None seen in > 1 year

3. **Safe**: Does the ass’y still work?
   Yes, after *more than 10X* the plating time to get a 2-3 \( \mu\text{m} \) Ni cap
Effective? - Ni Applied To This HL Instruments Commercial Product
Is the Metal-Capping Process Safe?

1. Every assembly still functions after immersion
   - No failures

2. Assembly is clean:
   
   **C3**: In steam extract of surface, with 10 VDC across || electrodes, measure time to 500 µA
   
   **Ion Chromatography**: In steam extract of surface, measure anion (e.g., Cl⁻, SO₄⁻) concentration
   
   **SIR**: After 1-month THB, measure surface insulation resistance on “umpire” assembly
   
   Foresite results: “Well above J-STD-001 requirements”
Critical Contamination Control → C3 Test Cell

High-purity 130°C steam in

Procedure
At selected site, do this 9X:
1. 300-msec steam
2. 20-sec soak
3. 2-sec aspirate & collect

Yields ~ 2½ cm³ extract

Apply 10 VDC across || electrodes
Measure time to 500 µA, else stop at 3 minutes
“Clean” ≡ > 60 sec.

Our thanks to Terry Munson

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www.Residues.com
Foresite Contamination Test Results

C3 time to 500 µA > 60 sec? *All sites timed out at 3 minutes*

Ion Chromatography

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<th>Ion species</th>
<th>Weak organic acids</th>
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Maximum observed reading (normalized to Foresite limits)

SIR – Surface Insulation Resistance *Minimum* > 10X the 10<sup>8</sup>-ohm Requirement

Our thanks to Terry Munson
Conclusions

*Prevention* now easier than *mitigation*

Three capping concepts for *assemblies*

– A ceramic, 200 nm *impenetrable*
– A polymer, designed to thickly cover all surfaces
– Selective metal cap
  *Not a new process*
  Novelty is its *application* to assemblies instead of bare board
  *50 nm Ni, Pd, AuSn₂* *impenetrable*
– Any of these processes enables *abandoning mitigation*
– You’re delivering hardware with a known failure mode
  *Hoping* that TWs puncturing conformal coat won’t short
– Now you can increase your hardware’s reliability
  *If* you believe capping *prevents* TW penetration
  *If* your management believes capping *prevents* TW penetration
  *If* your customer believes capping *prevents* TW penetration
Conclusions – Metal Cap Process

• **Safe**
  – No loss of function on capped assemblies
  – Foresite data ⇒ ordinary rinsing gets it clean

• **Effective**
  – Some metals *prevent* TW penetration *permanently*
  – For Ni, $\theta_{\text{Ni}}^m \approx 35$ nm
  – **Safety margin** for 1-µm cap: 1½ *orders of magnitude*

• **Practical**
  – **Time** for 1-µm cap: 2-3 minutes
  – Close match to description of *Ideal TW-prevention* capping process