Preventing Tin Whisker Growth Risk

Bob Landman, Gordon Davy, Dennis Fritz
LDF Coatings, LLC

We have the solution.

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.

Tin Whisker Facts

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.

LDF COATINGS www.LDFcoatings.com We have the solution.

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.

LDF COATINGS www.LDFcoatings.com We have the solution.

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”

TheTW *Prevention* Challenge

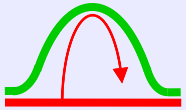
Find a TW *prevention* means more practical than component termination finish replacement

- 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? ☹

LDF COATINGS www.LDFcoatings.com We have the solution.

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 *selectively* on Sn and other metals



1. TW *tents* the cap
2. Cap *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

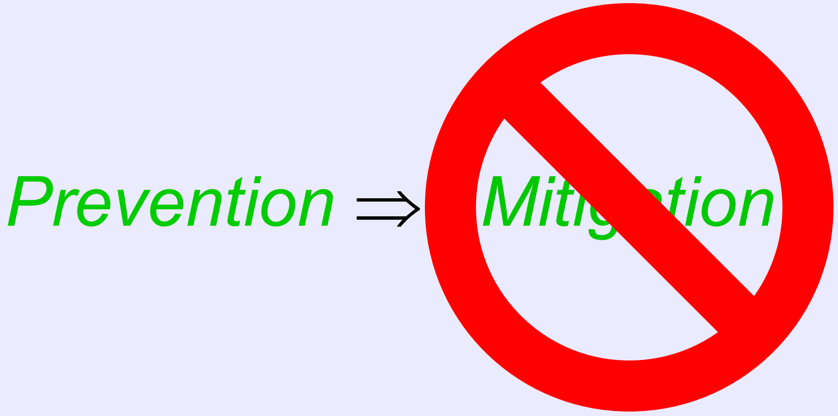
TW mitigation means now in use are *marginal*

∴ 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 ⇒ *Mitigation*

Prevention replaces, not augments, *mitigation*

LDF COATINGS
www.LDFcoatings.com
We have the solution.

New topic – Process

Req’ts 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

LDF COATINGS www.LDFcoatings.com We have the solution.

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*?

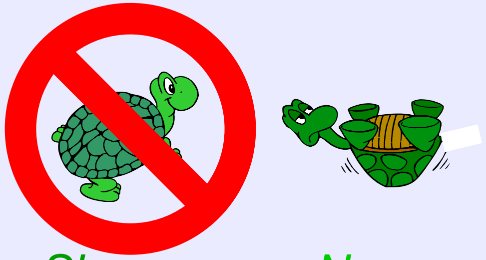
Selective Metal Cap Layer Process For Coating Sn on Assemblies

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



Reactions

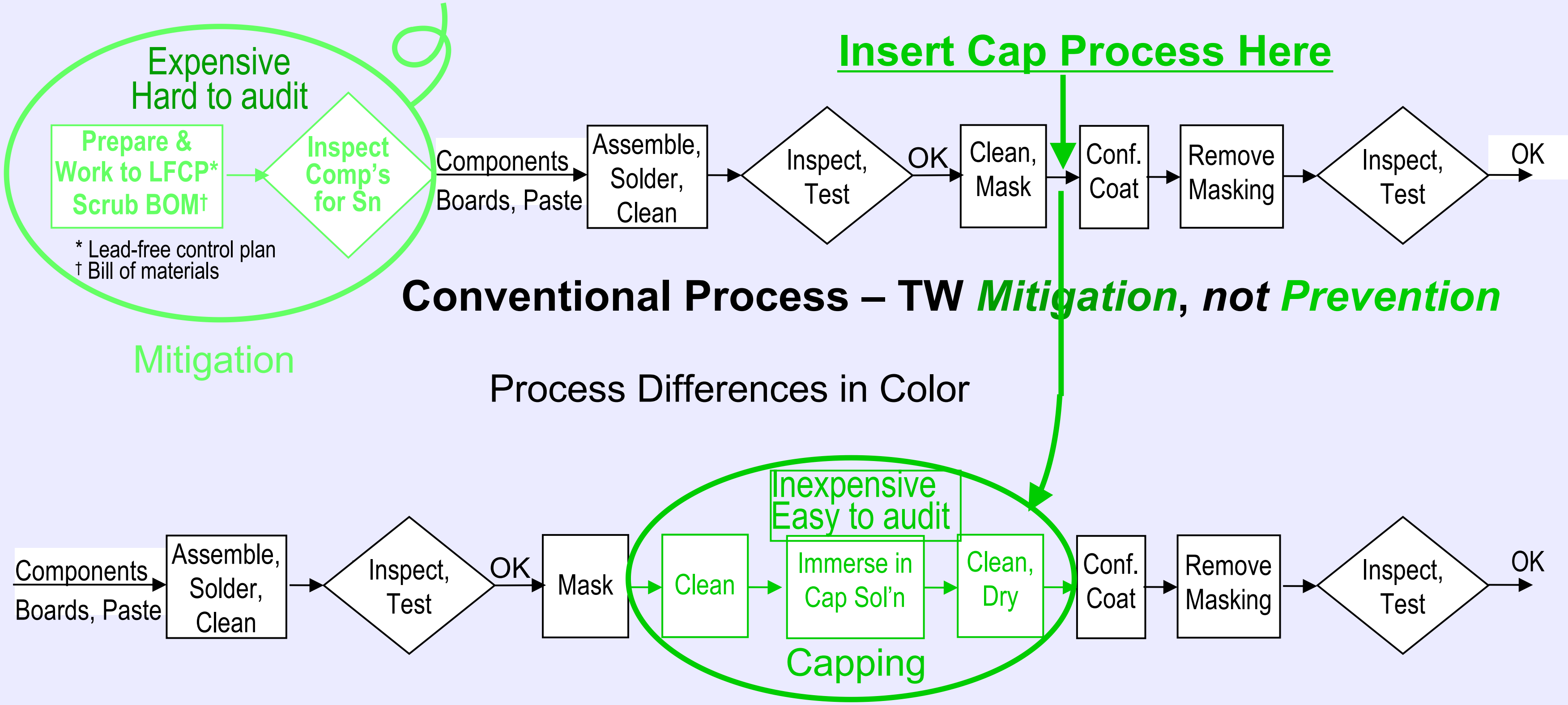
- Are you crazy? I'd *never* put any assembly of *mine* in a *plating bath!!!*
  - Why not?
  - You *do* remove flux by aqueous cleaning, right?
  - Are you "data-driven" or "intuition-driven"?
- But, but – that's never been *done* before!!!
  - And your point?
- Will *all* the Sn plate?
  - Electroless 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*



Expensive
Hard to audit

Prepare & Work to LFCP* Scrub BOM† → **Inspect Comp's for Sn**

* Lead-free control plan
† Bill of materials

Mitigation

Components → Boards, Paste → Assemble, Solder, Clean → Inspect, Test → OK → Clean, Mask → Conf. Coat → Remove Masking → Inspect, Test → OK

Insert Cap Process Here

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

Process Differences in Color

Components → Boards, Paste → Assemble, Solder, Clean → Inspect, Test → OK → Mask → Clean → Immerse in Cap Sol'n → Clean, Dry → Conf. Coat → Remove Masking → Inspect, Test → OK

Inexpensive
Easy to audit

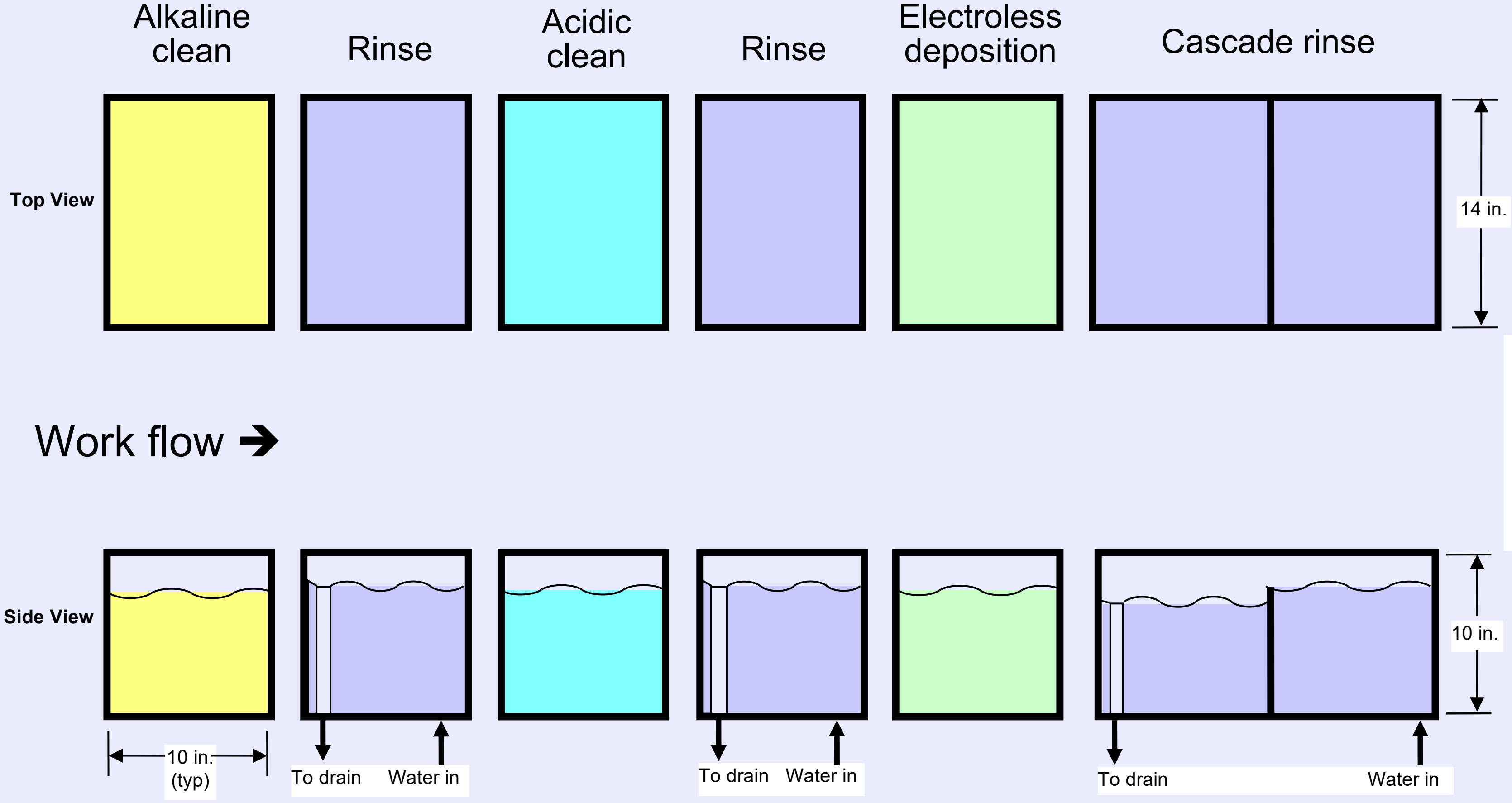
Capping

New TW-*Prevention* Metal-Capping Process

Ceramic- and polymer-capping processes similar

LDF COATINGS
www.LDFcoatings.com
We have the solution.

Electroless Plating System Layout Scale Model



Alkaline clean

Rinse

Acidic clean

Rinse

Electroless deposition

Cascade rinse

Dry station

Work flow ➔

We have the solution.

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 ± 0.2 μm Ni, 2 assemblies, 3 locations ea.

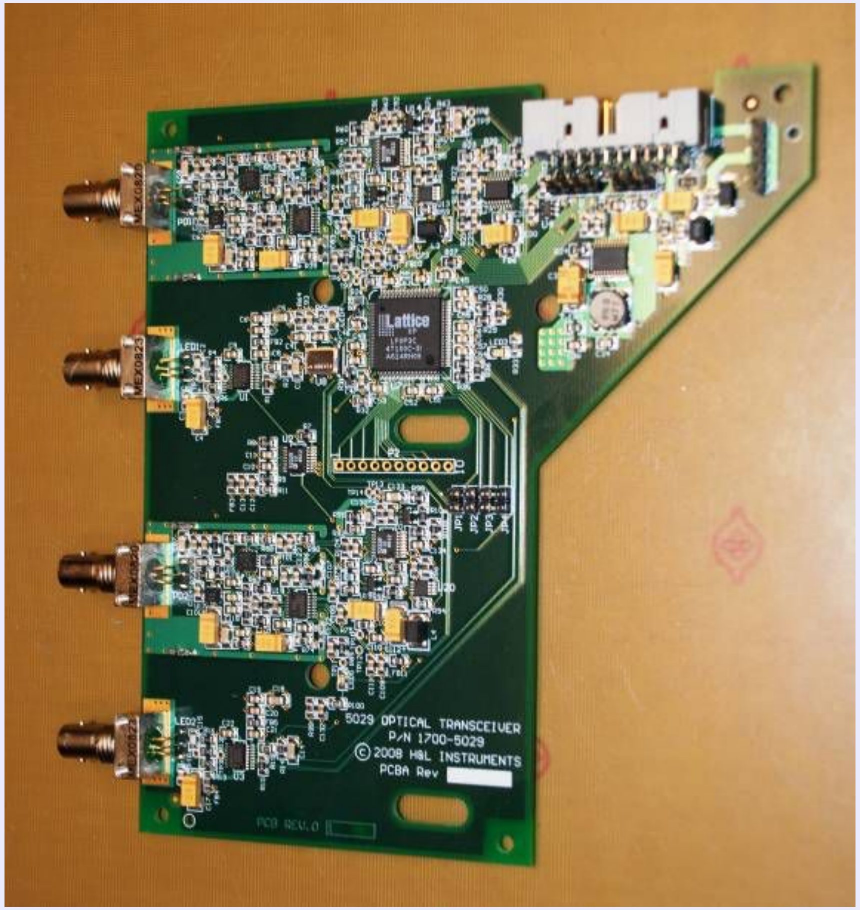
2. *Effective:* Have TWs penetrated?

   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 μm Ni cap

Effective? - Ni Applied To This HL Instruments Commercial Product



We have the solution.

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^-, $SO_4^=$) 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:

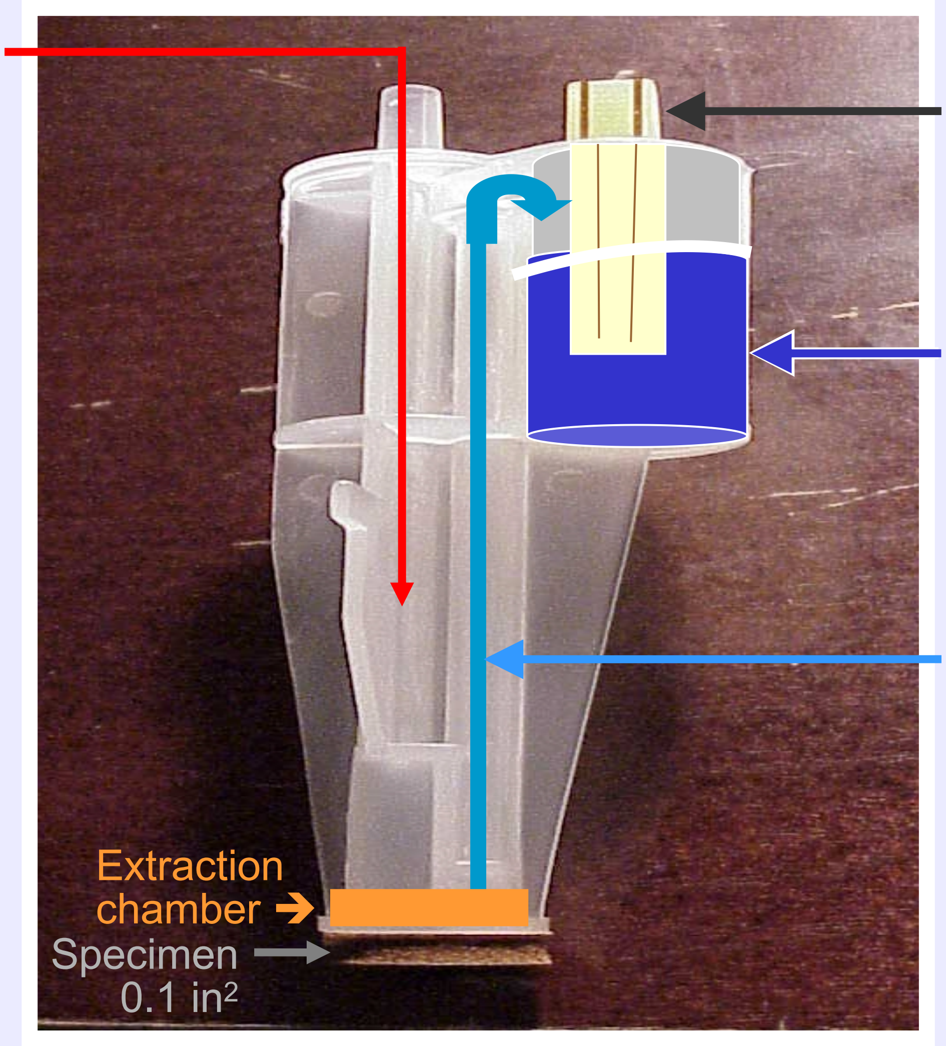
1. 300-msec steam
2. 20-sec soak
3. 2-sec aspirate & collect

Yields ~ 2½ cm^3 extract

Apply 10 VDC across || electrodes

Measure time to 500 µA, else stop at 3 minutes

“Clean” ≡ > 60 sec.



Substrate with || electrodes

Extract Collection Chamber

Aspiration Pathway

Extraction chamber ➔

Specimen → 0.1 in^2

Our thanks to Terry Munson

FORESITE

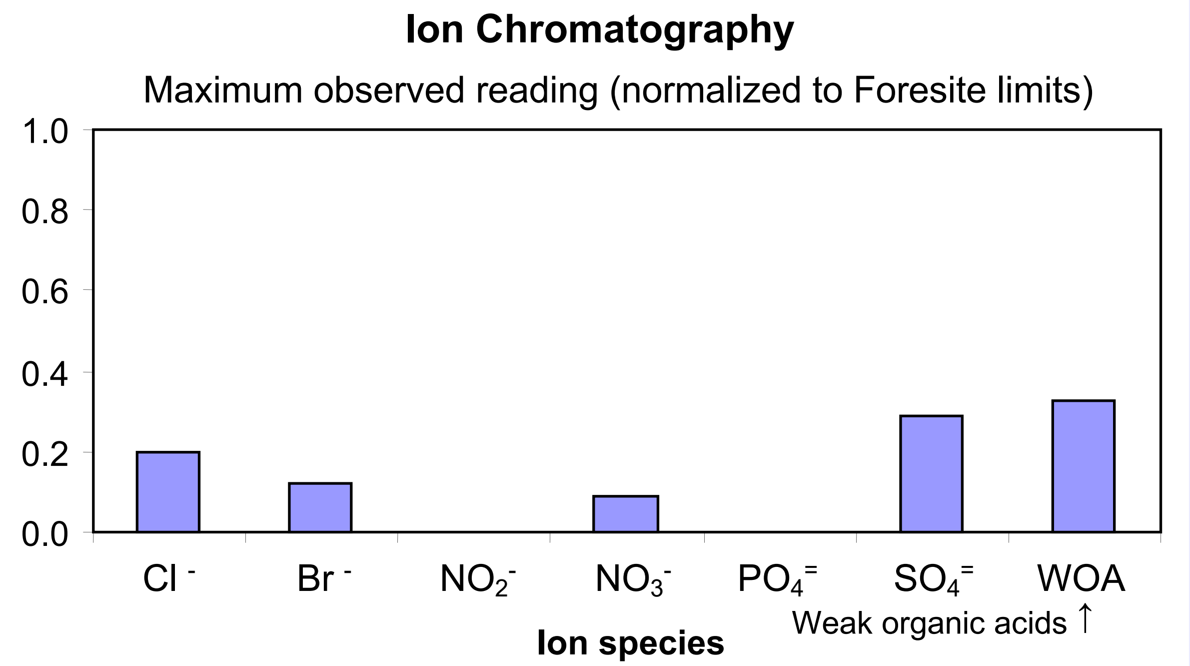
www.Residues.com

LDF COATINGS www.LDFcoatings.com ▶ We have the solution.

Foresite Contamination Test Results

① **C3 time to 500 µA > 60 sec?** ***All sites timed out at 3 minutes***

②



③ **SIR – Surface Insulation Resistance** ***Minimum*** **> 10X the 10^8-ohm Requirement**

Our thanks to
Terry Munson

www.Residues.com

LDF COATINGS www.LDFcoatings.com We have the solution.

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, $AuSn_2$ *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

LDF COATINGS www.LDFcoatings.com We have the solution.

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, $\theta_{Ni}^{m} \approx 35$ 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