Tin Whiskers in Electronics Components

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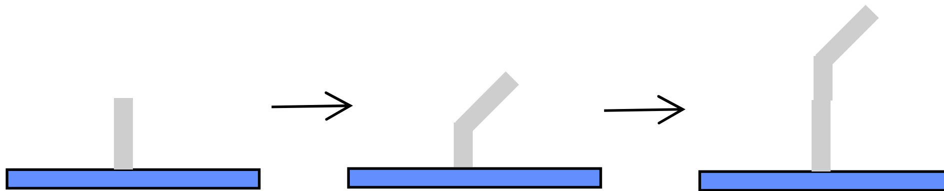
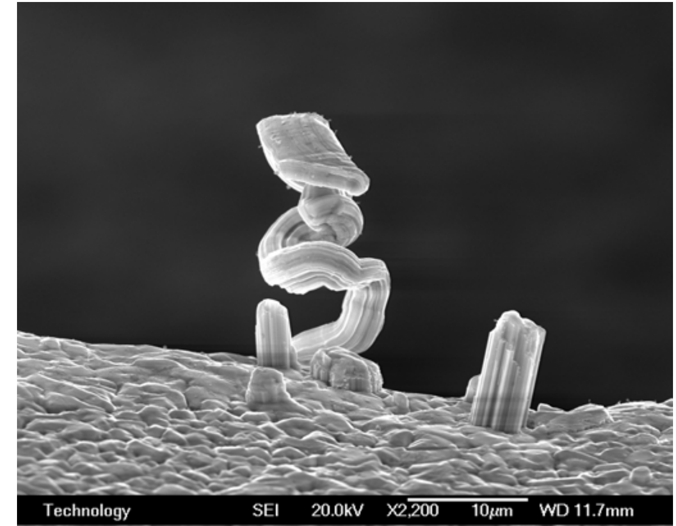
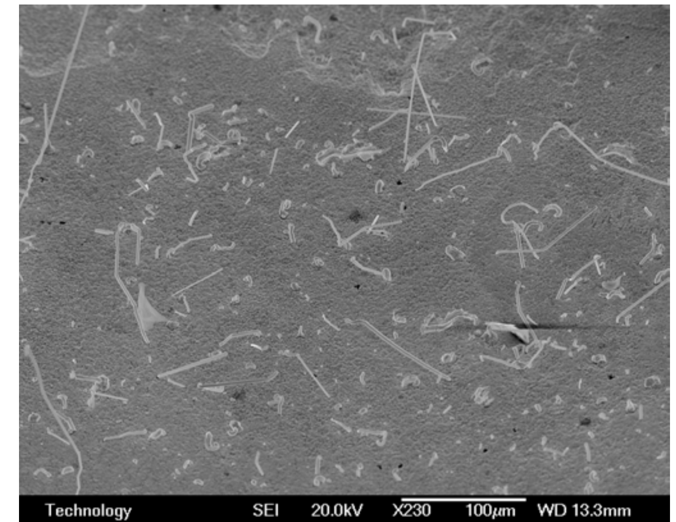
Tin Whiskers

- Tin whiskers are single crystals of tin that spontaneously grow from the surface of tin and tin alloy platings
- Whiskers can take many shapes and grow to lengths as long as several millimeters
- Whiskers can kink and bend during their growth. Growth occurs from the base of the whisker.



Whisker growth

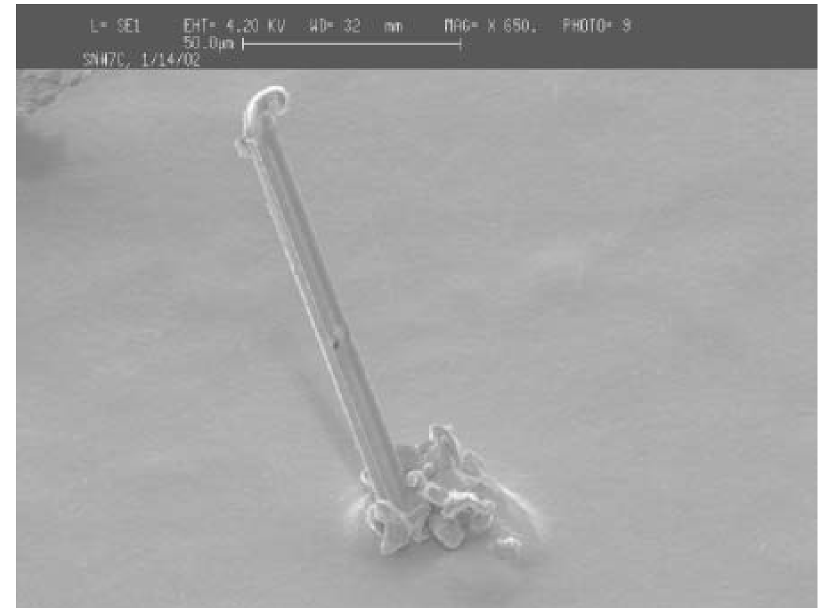




Whisker growth on tin

Tin Whiskers (2)

- Removing a tin whisker (by brushing for example) does not prevent future growth
- Tin whiskers can grow through thinner (100 µm) conformal coatings (like Parylene)
- Tin whiskers cannot grow through plastic housings and thick dielectric coatings
- High voltages will electrically break down whiskers. Whiskers are not a problem for power circuits, but may be an issue for surrounding circuitry.



Whisker growing through conformal coating, courtesy J. Brusse, NASA

Whisker Image: Filament on Bright Tin

334×
20.0 kV
100µm
RDH21AUG01
#0006*

Whisker Images: Whiskers Adjacent to Deformed Area

500× 20.0 kV 10μm RDH21AUG01 #0005*

Whisker Images: Small Whiskers on Matte Tin over Nickel

As-plated & Assembled

SEI

1µm

5,000× 20.0 kV jsc08nov04 #0010*

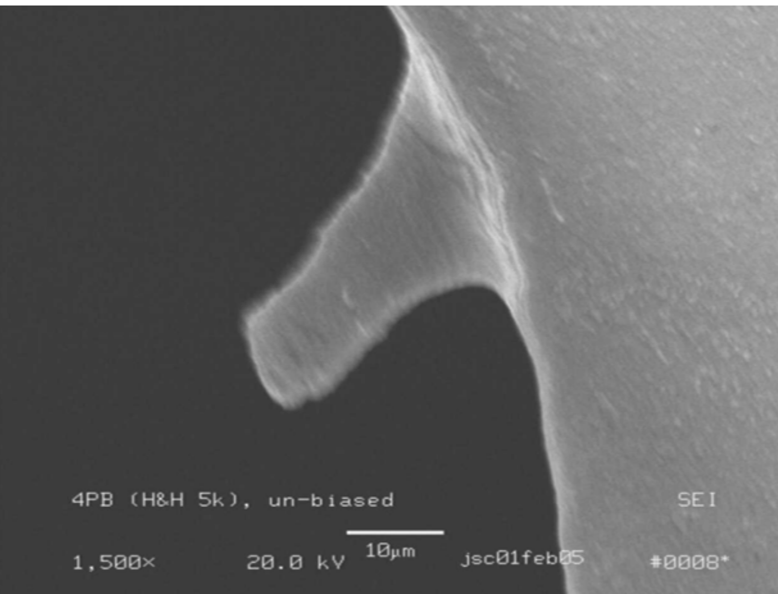
Whisker Images: Grain Boundary Sinking Adjacent to Whisker Grain

As-plated & Assembled

1,000× 20.0 kV 10μm jsc08nov04 #0010*

Tin Whiskers Growth is Reduced by:

- Adding lead to tin (3% minimum lead required)
  - There is no alloying replacement for lead as a whisker mitigator
  - Even tin/lead platings occasionally form whiskers
    - These are typically small, on the order of 20µm in length
- Avoiding compressive stress situations
- Using reflowed tin or hot tin dip



Tin/lead whiskers

FIB section showing Cu-Sn intermetallic

Copper tin intermetallic forming at the base of a tin whisker root and along the whisker grain boundaries.

Image courtesy of Chen Xu, Cookson Electronics

Whisker can grow preferentially in deformed areas, especially in susceptible tin platings

No whiskers here

Tip damage
Due to trim and form

100µm

326× 20.0 kV RDH26JAN05 #0505*

Whiskers grow where tin has been stressed

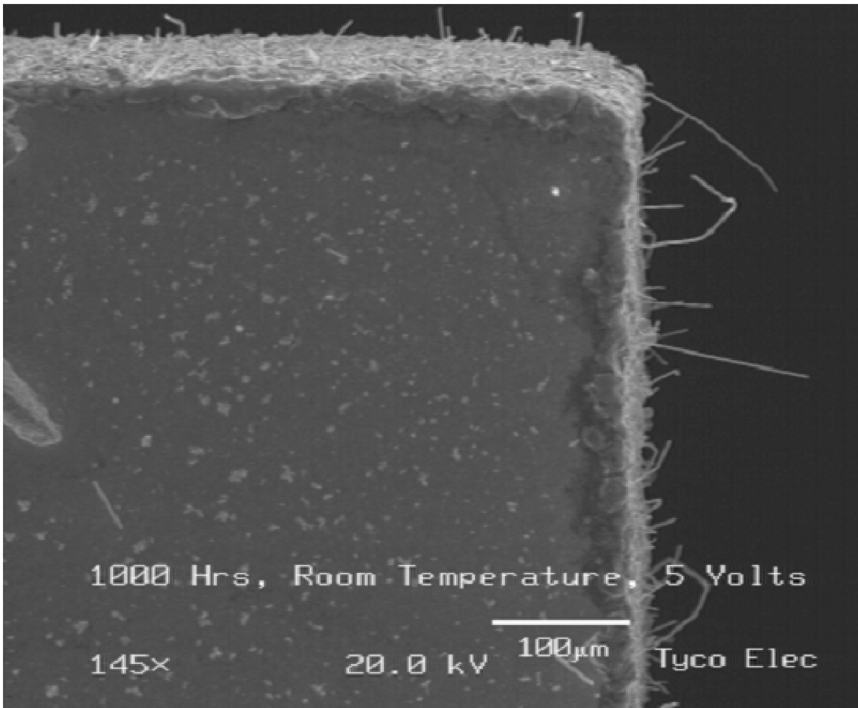
How do we deal with whiskers?

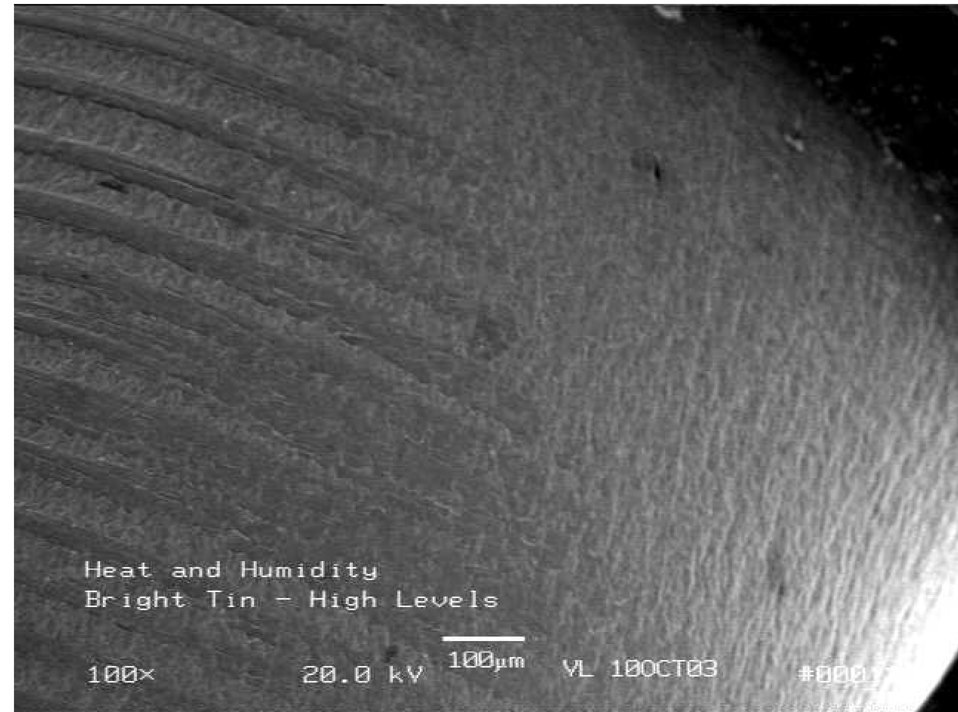
- Key issues to control whisker growth are:
  - Plating bath selection
    - Matte tin preferred
      - low carbon content
      - low as plated stress
      - optimized crystallographic orientation
  - Avoid intermetallic growth
    - Use a Ni barrier of 1.27um min
  - Use reflowed tin when possible
  - Reduce stress on the tin
  - Test, Test, Test
    - NEMI User's Test Method
    - NEMI DOE3 results

Matte Tin vs. Bright Tin

- Matte tin:
- Customer preferred finish
- Use with Ni barrier
- Some matte tins perform poorly

- Bright Tin:
- Industry bias against its use
- Use with a Ni barrier
- Some bright tins perform well





Whiskers: Role of intermetallics

- Intermetallics form when Cu and Sn are available to interdiffuse
- The formation of Cu_6Sn_5 intermetallic increases the compressive stress in the tin deposit which can increase whiskering.

FIB section showing Cu-Sn intermetallic

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Image courtesy of Chen Xu, Cookson Electronics

Whiskers: Role of intermetallics

- Intermetallics form when Cu and Sn are available to interdiffuse
- The formation of Cu_6Sn_5 intermetallic increases the compressive stress in the tin deposit which can increase whiskering.
- The predominant method of reducing the growth of copper-tin intermetallics is to add a diffusion barrier, such as nickel.
- While nickel can also form intermetallics with tin, they result in a tensile stress in the plating.
- Nickel has been shown to drastically retard the formation of whiskers

Intermetallic Growth Rate of Tin Based Platings (Square Root of Time)

Intermetallic growth rate of tin based platings over copper at various temperatures. Blue lines are for tin over nickel with Ni_3Sn_4 Intermetallic.

Average

Sn at 50°C

60% Sn 40% Pb at 50°C

90% Sn 10% Pb at 50°C

Sn over Ni @ 50 C

Sn at 24°C

60% Sn 40% Pb at 24°C

Sn over Ni @ 24 C

90% Sn 10% Pb at 24°C

Intermetallic Thickness, μ"

0 10 20 30 40 50 60 70 80 90 100 110

0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30

(0.5 Years) (1 Year) (2 Years)

$\sqrt{\text{Time (Days)}}$

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But..

- A nickel barrier combined with the right tin plating mitigates whiskers. Nickel barriers alone cannot prevent whiskers from forming…

Anatomy of a Tin Whisker: Focused Ion Beam Section of a Tin Whisker

Matte tin surface

Whisker, single crystal of tin

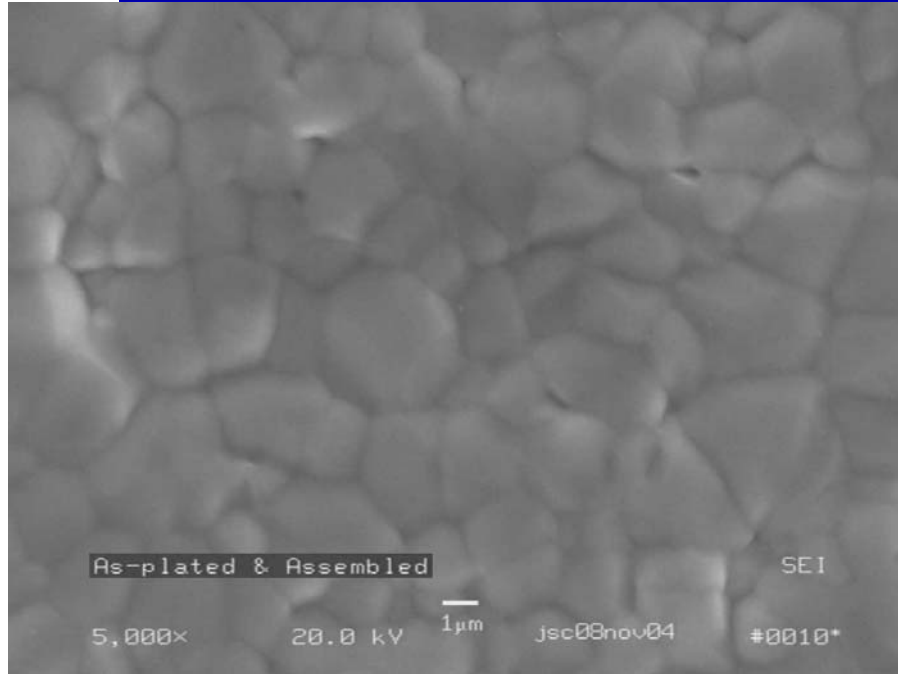
Tin cross-section

Ni cross-section

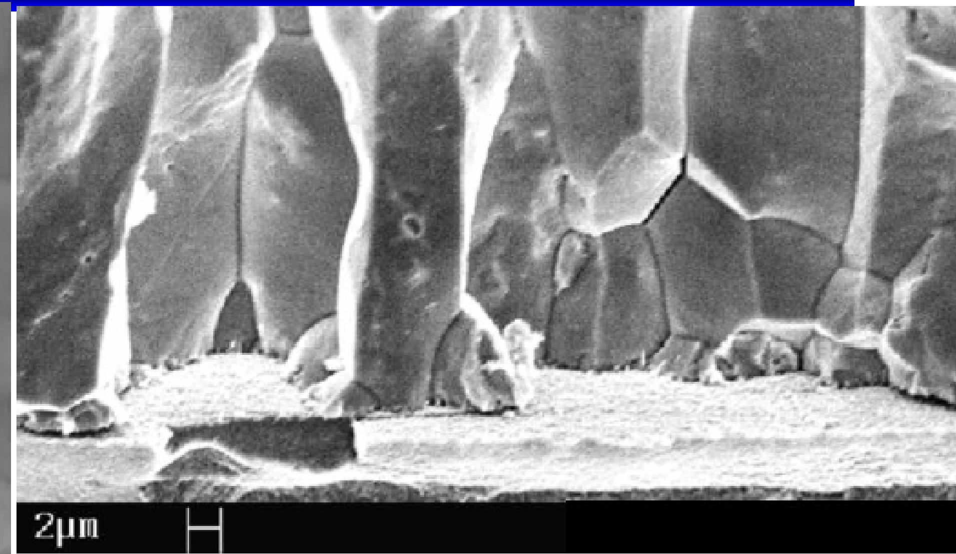
Cu base

Beam	Det	Scan	Mag	FWD	Tilt	pA	10 µm
30.0 kV	CDM-E	H 45.26 s	3.50 kX	18.0	44.6°	4.00	

Matte tin plating – large grains



Typical matte tin grain morphology in Tyco plating



Freeze fracture image of a matte tin deposit showing the increase in grain size as a function of plating thickness. This is a very thick film.
Image Courtesy of P. Kuhlkamp, Atotech

Reflowed tin has reduced tin whisker growth

Surface of tin showing clear evidence of reflow

Re-flowed & Assembled SEI

5,000x 20.0 kV 1µm jsc08nov04 #0025*

Overview of Typical iNEMI Testing

- Tyco is an iNEMI member and has participated in developing the iNEMI test conditions, Users Group Acceptance document and also on the whisker fundamentals team.
  - We also participate in tin whisker standards development with IPC, JEDEC, JEITA and IEC
- 3 Test Segments: 2 isothermal and 1 Temperature Cycling of NEMI “Tin Whisker Growth Test”
  - Ambient/Storage (20-25ºC, 30-80% RH)–minimum* 4000 Hrs
  - Aging/Temperature & Humidity (60ºC, 93%RH)–minimum* 4000 Hrs
  - Thermal Cycling (-55ºC to + 85ºC)–minimum* 1000 cycles

    * Test Durations may be longer depending on results (more later)
- Tests are extended to include assembly preconditioning and bias to represent actual use conditions
- Tests must generate whiskers on some samples (can be intentionally added coupons or components) to ensure validity

Test Components

- Components must be representative of the actual products that the finish to be tested shall be applied to
  - Can be qualified by “Like Construction”
  - Bias test must use devices with the minimum lead-pitch to be qualified
    - Bias testing link
- Plating Method
  - The plating method and supplier(s) used for plating shall be the production plating and supplier proposed for qualification
  - Each plating supplier (internal and external) shall be qualified according to our specification

Qualification by Similarity

- Tyco's history has shown that tin whisker growth can be influenced by the plating process and its control.
- We have tested over 150 unique commercial or developmental tin based plating formulations
  - Many perform poorly in tin whisker testing
  - Most are MSA based
  - Sn, Sn-Ag, Sn-Bi, Sn-Cu
  - Matte and bright tin
- Once a plating process is approved, it can be used on similarly constructed plating lines with only minor testing
  - MUST be operated within the process operation window defined by our whisker evaluation window (next page).

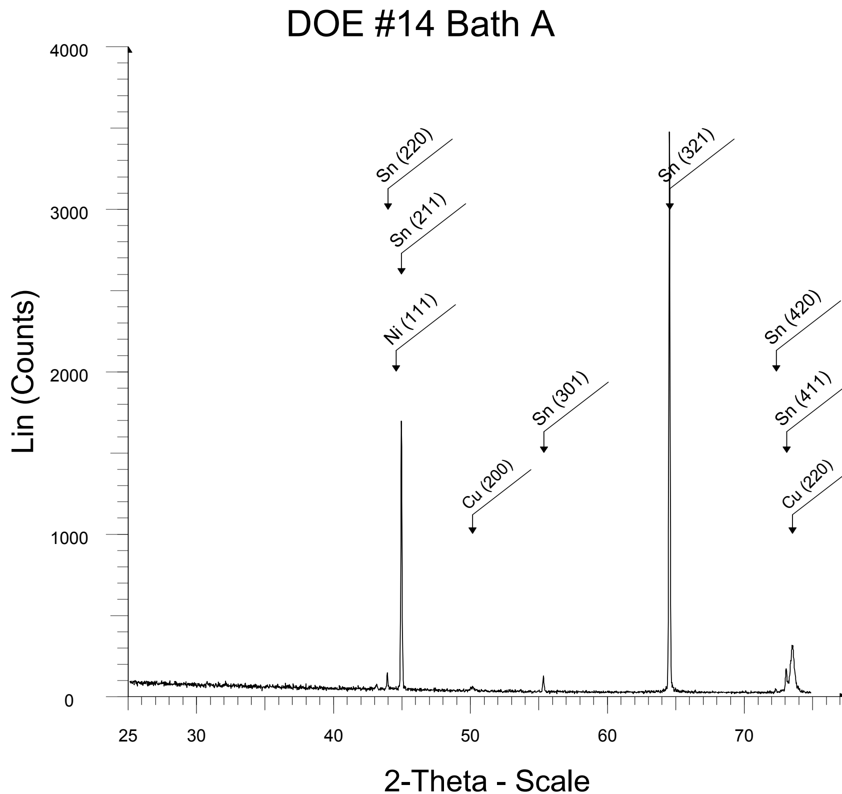
Qualification

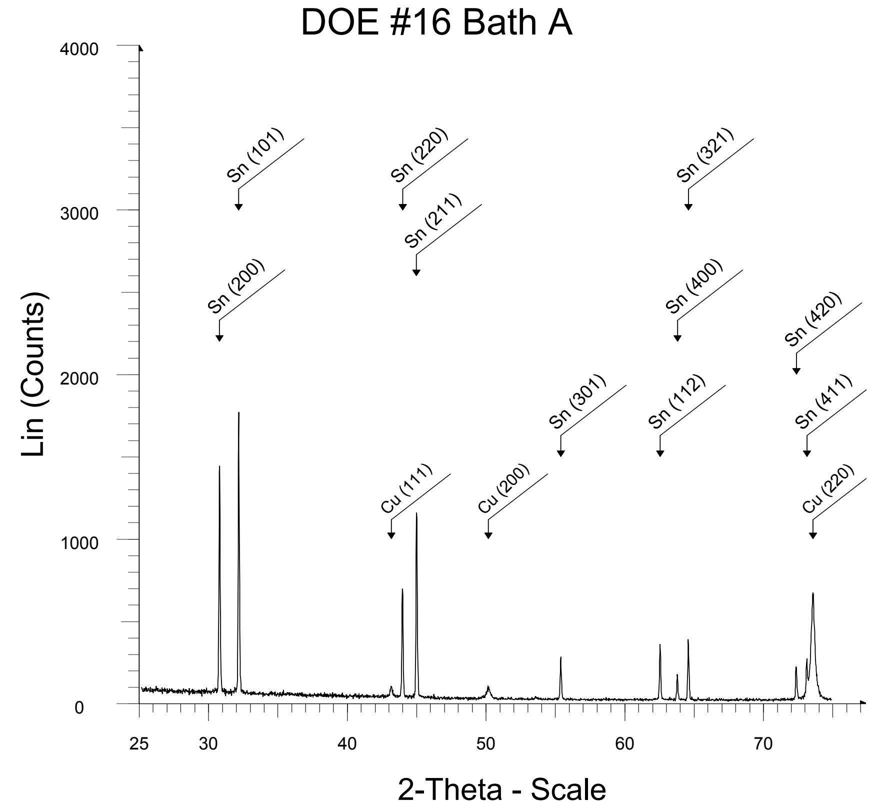
- Our testing uses a DOE approach to evaluate plating parameters
  - Metal content
  - Acid content
  - Additive levels (one, two ore three components)
  - Current density
  - Agitation
  - With and without a Ni barrier

Typical DOE Matrix

Test No.	Variable						
	1	2	3	4	5	6	7
	Metal	Acid	Bath Additive	Bath Additive	Current Density	Agitation	Ni Underplate
1	1	1	1	1	1	1	1
2	-1	1	1	1	-1	1	-1
3	1	-1	1	1	-1	-1	1
4	-1	-1	1	1	1	-1	-1
5	1	1	-1	1	-1	-1	-1
6	-1	1	-1	1	1	-1	1
7	1	-1	-1	1	1	1	-1
8	-1	-1	-1	1	-1	1	1
9	1	1	1	-1	1	-1	-1
10	-1	1	1	-1	-1	-1	1
11	1	-1	1	-1	-1	1	-1
12	-1	-1	1	-1	1	1	1
13	1	1	-1	-1	-1	1	1
14	-1	1	-1	-1	1	1	-1
15	1	-1	-1	-1	1	-1	1
16	-1	-1	-1	-1	-1	-1	-1

Two X-Ray Diffraction Patterns





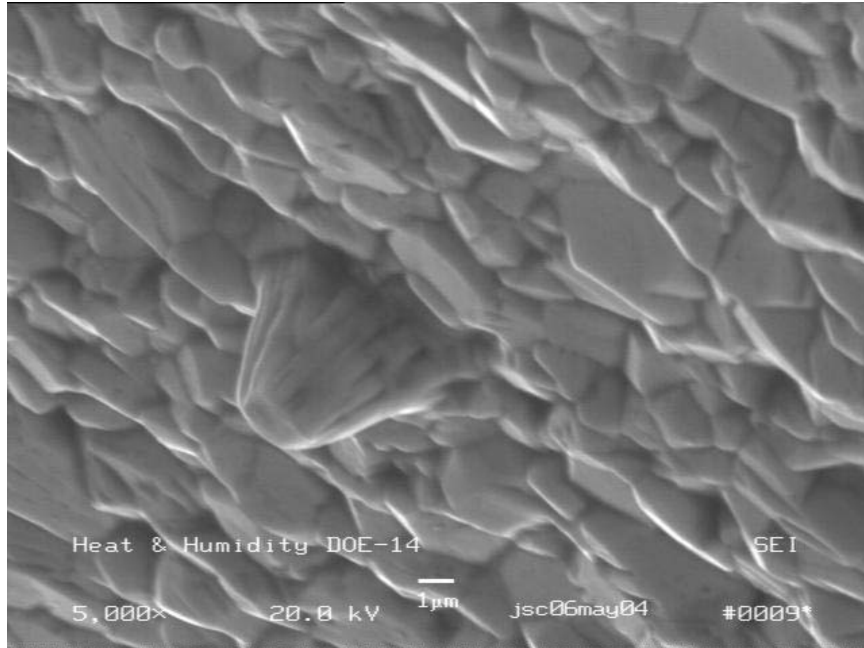
Same plating bath (matte tin) run under two different plating conditions

Process on left (#14) grows whisker 5um long while

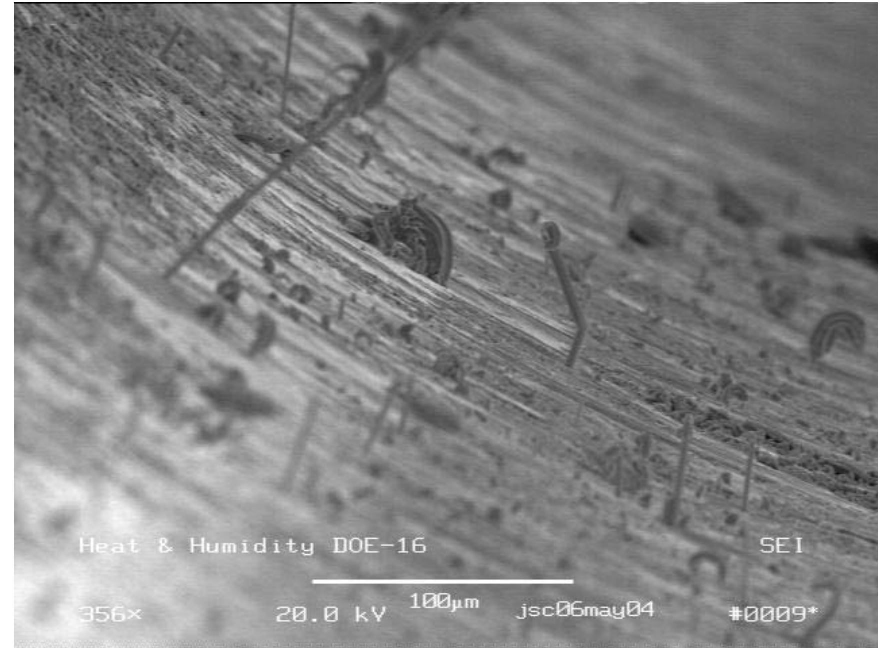
process on right (#16) grows whiskers > 200 um long

Very different orientation based on X-Ray diffraction spectra

Comparative Whisker Performance



DOE condition #14 – small whiskers (5um) only after 5000 hours of heat and humidity conditioning



DOE condition #16 – long whiskers (>200 um) after 5000 hours of heat and humidity conditioning

DOE Results for 5000 hours of Heat and Humidity: Strong Effect of Ni Barrier

Test No.	Ni Underplate	Max. Whisker Length (μm)
16	No	450
5	No	300
2	No	110
9	No	50
10	Yes	10
4	No	5
7	No	5
11	No	5
14	No	5
1	Yes	5
6	Yes	5
15	Yes	5
13	Yes	3
3	Yes	0
8	Yes	0
12	Yes	0

DOE Results for 8500 Hours of Room Temperature Storage: Strong Effect of Ni Barrier

Test No.	Ni Underplate	Max. Whisker Length (μm)
2	No	100
4	No	50
7	No	50
9	No	40
14	No	30
11	No	20
13	Yes	5
15	Yes	5
1	Yes	0
3	Yes	0
5	No	0
6	Yes	0
8	Yes	0
10	Yes	0
12	Yes	0
16	No	0

DOE Results for 3000 Cycles of Thermal Shock: Strong Effect of Ni Barrier

Test No.	Ni Underplate	Max. Whisker Length (μm)
9	No	40
4	No	30
14	No	30
2	No	20
5	No	10
7	No	10
6	Yes	5
10	Yes	5
11	No	5
15	Yes	5
13	Yes	3
1	Yes	0
3	Yes	0
8	Yes	0
12	Yes	0
16	No	0

Ongoing inspection

- One concern with tin whisker quality is the inability to inspect for whisker risk during manufacturing.
- We have empirically correlated plating process, the resulting microstructure and whisker performance.
  - It is not entirely known if these factors control whisker growth
- On-going inspection
  - Pull one part per plating line per week
  - Part is stored at ambient conditions in the plating shop
  - Parts are inspected at 3 and 6 month intervals for signs of whisker growth

Assembly and Reflow effects

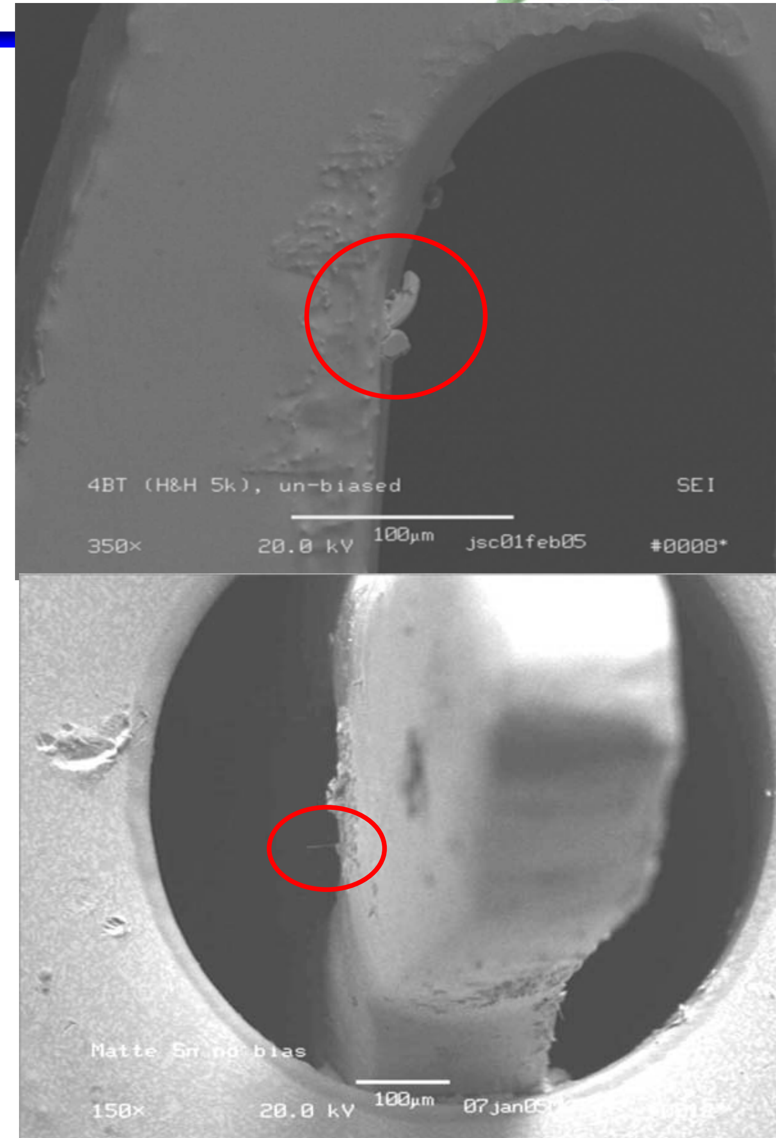
- Soldering components to a board using a lead free profile will reflow the tin layer.
- This reduces stress in the tin and increases the grain size of the tin layer;
  - Hence, the whiskering tendency goes down
- Table below is for tin over nickel plating performance after six months of aging (60C/93%RH) with and without simulated lead free solder reflow.

Table of maximum whisker length

Plating bath	Reflowed	As-plated
Tyco Plating Process	15 um	30 um
Developmental process – not implemented	20 um	180 um

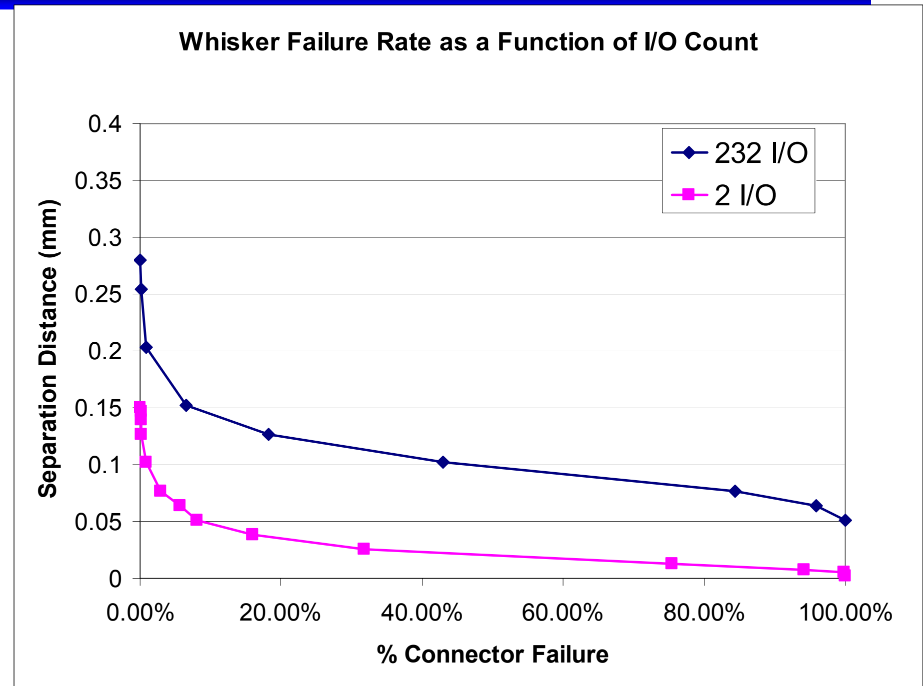
Tin over Nickel in Press-fit Applications

- ❑ Tin plating over nickel appears Ok for press-fit products
- ❑ Matte and Bright tin perform well
  - Must be using a “known good” plating process
- ❑ Testing to date has been on eye of the needle type designs
- ❑ Whisker growth is most common in the interior portions of the contact (where compressive stress is highest)



Spacing issues

- Parts with greater spacing between contacts (not pitch) are less likely to have reliability problems from whiskers
- This graph shows the simulated likelihood for electrical short (failure) based on separation distance between contacts
- This is based on Monte Carlo simulation of Tin Whisker growth on tin that is highly stressed



Simulated failure rates were nil, and thus trivial, for unstressed, whisker mitigated tin

Reference: Hilty and Corman, IPC/JEDEC 8th International Conference on Lead Free Electronics, San Jose, CA, April 18-20, 2005.

Spacing versus pitch

Image of a connector with 1mm pitch, but with only 0.3mm spacing between the contacts

Thermal Cycling

- Thermal cycling conditions lead to a compressive stress in the tin due to coefficient of thermal expansion (CTE) mismatch between tin (CTE ~ 23ppm/C) and some base metals
- Most prevalent in low CTE materials, such as alloy 42 (CTE ~ 4 ppm/C) used for lead frame devices.
- Tin whisker growth can be rapid for these situations.

Thermal Cycling and Alloy 42 Base Metals

- Pure tin is not a recommended finish for this base metal if tin whiskers are of concern
- Adding a nickel barrier will not retard whisker formation
  - Iron-tin intermetallics are very slow to form in the solid state and do not drive whisker growth.
- Ni/Pd/Au finishes are the industry standard for these applications
  - In many IC applications there is no cost increase due to other benefits of using this coating
- There has been some success reported with Sn-Bi coatings on alloy 42, but this data is somewhat disputed and not yet considered reliable.
  - Sn-Bi has other issues, both technical and logistical

Impurity Effect on Whisker Growth

- Impurity tests, as shown below, performed on matte and bright tin
- No significant difference in whisker performance after
  - Heat age; heat/humidity; room temp storage; thermal cycling

Sample	Tin with these contaminants:
A	Thin tin with no added impurities
B	10 ppm Cu; 10 ppm Ni; 10 ppm Zn
C	10 ppm Cu; 10 ppm Ni; 10 ppm Zn; 1 ppm Fe
D	10 ppm Cu; 10 ppm Ni; 10 ppm Zn; 1 ppm Fe; 10 ppm Na; 10 ppm Ca
E	100 ppm Cu; 100 ppm Ni; 100 ppm Zn; 1 ppm Fe; 10 ppm Na; 10 ppm Ca
F	100 ppm Cu; 100 ppm Ni; 100 ppm Zn; 1 ppm Fe; 100 ppm Na; 100 ppm Ca

Other Plating Defects

- Under the wrong plating conditions, you can grow tin dendrites
- These are not tin whiskers

Tin Whisker Test Results

- Tyco Electronics plating process:
  - a low whiskering plating process
  - capable of meeting class 2 performance as per the NEMI standard
    - Less than 40 um average maximum whisker length
- Heat and humidity conditioning accelerates tin whisker growth most expeditiously
- There can be an incubation period in excess of 1000 hours for some tin platings to develop any whisker growth
- When tin whiskers form, they are more likely to form in areas under compressive stress
  - Contact retention areas, post-plate bending, trim and form locations