Examination of Nickel Underlayer as a Tin Whisker Mitigator

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Tin Whisker: an Introduction

- Tin Whisker - conductive crystalline structure of tin growing outward from tin rich surfaces
- Whiskers are formed through addition of atoms at the base, not the tip
  - Lengths vary from few micrometers to millimeters
  - Thicknesses range typically 0.5-10µm
  - Whisker densities may range from just a few whiskers to thousands per component
  - This process may take hours, days, or years
- Long range diffusion responsible for tin transfer to site of whisker growth
- Types of Failures induced by Whiskers:
  - Electrical short circuit
    - ***Permanent*** if Current < Melting Current
    - ***Intermittent*** if Current > Melting Current
  - Metal Vapor Arc
    - Applications with high levels of current and voltage may cause whisker vaporizing into conductive plasma of metal ions
    - Plasma forms an arc capable of sustaining hundreds of amps

Mitigating Tin Whiskers

Mitigation ≠ Elimination

To mitigate – to make less severe or painful

Merriam-Webster Dictionary definition

- Use of SnPb or Sn-free surface finishes
  - Avoid using Zn or Cd surfaces – they whisker too!
  - Hot Solder Dip in SnPb, if practical
- Use of conformal coating of sufficient thickness
- Mitigation strategies that have been suggested, yet contradictory data exists regarding their success
  - Heat Treatment (Reflow, Annealing)
  - Thicker tin finish
  - Matte tin (Note: No Standard definition of Matte vs Bright finish)
  - SnBi, SnAg alloys
  - Underlayer (Ni, Ag)

Standards for Assessing Whisker Growth

This talk is not an endorsement of these standards, as will be evident from the following slides

Standard	IEC60068-82-2	JESD22-A121A (†)
Issue Date	2007/5	2008/7
Ambient Storage	30°C, 60%RH or 25°C, 55%RH 4000 hrs	30°C, 60%RH
Elevated Temperature Humidity Storage	55°C, 85%RH 2000 hrs	55°C, 85%RH 60°C, 87% RH (*)
Temperature Cycling	Min: -55°C or -40°C Max: 85°C or 125°C 1000 or 2000 Cycles	Min: -55°C or -40°C Max: 85 (+10/-0) °C 1000 or 2000 Cycles
Acceptance Criteria	50µm	--

(†) JESD22-A121A does not prescribe duration of tests or Acceptance criteria. JESD201 should be used for that

(*) Earlier version JESD22-A121, published May 2005

Whisker Length Definition

JESD22-A121(May 2005)

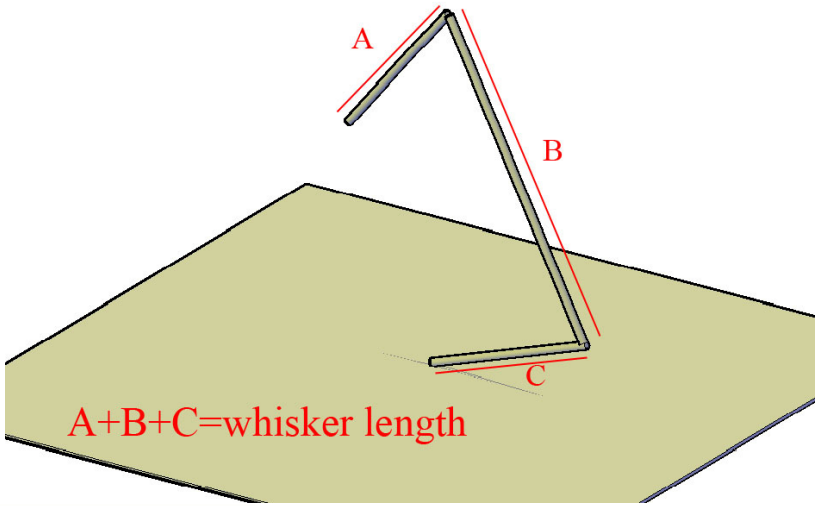
The distance between the finish surface and the tip of the whisker that would exist if the whisker were straight and perpendicular to the surface

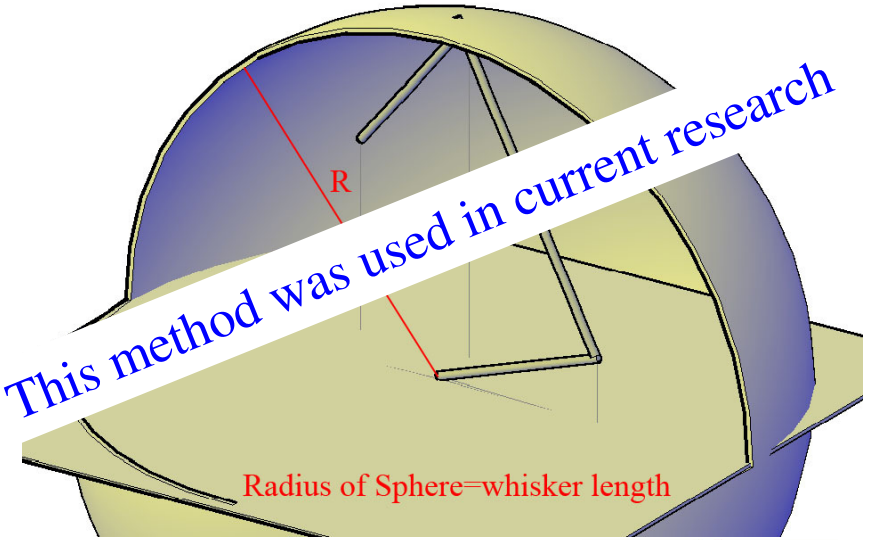
JESD201 (March 2006)

JESD22-A121A (July 2008)

IEC 60068-2-82 (May 2007)

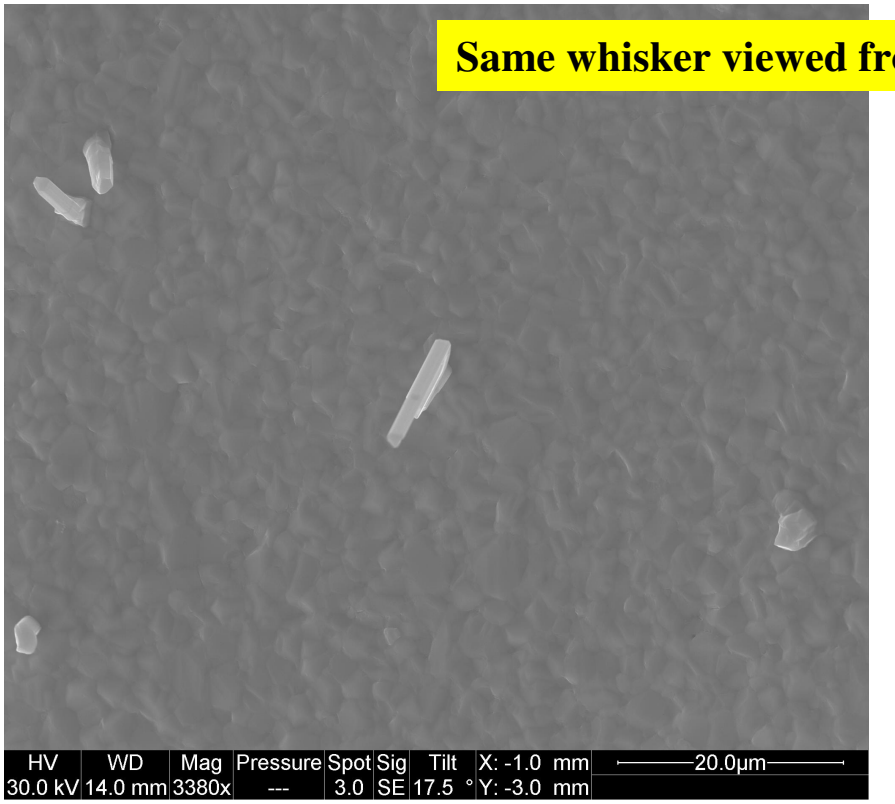
The straight line distance from the point of emergence of the whisker to the most distant point on the whisker

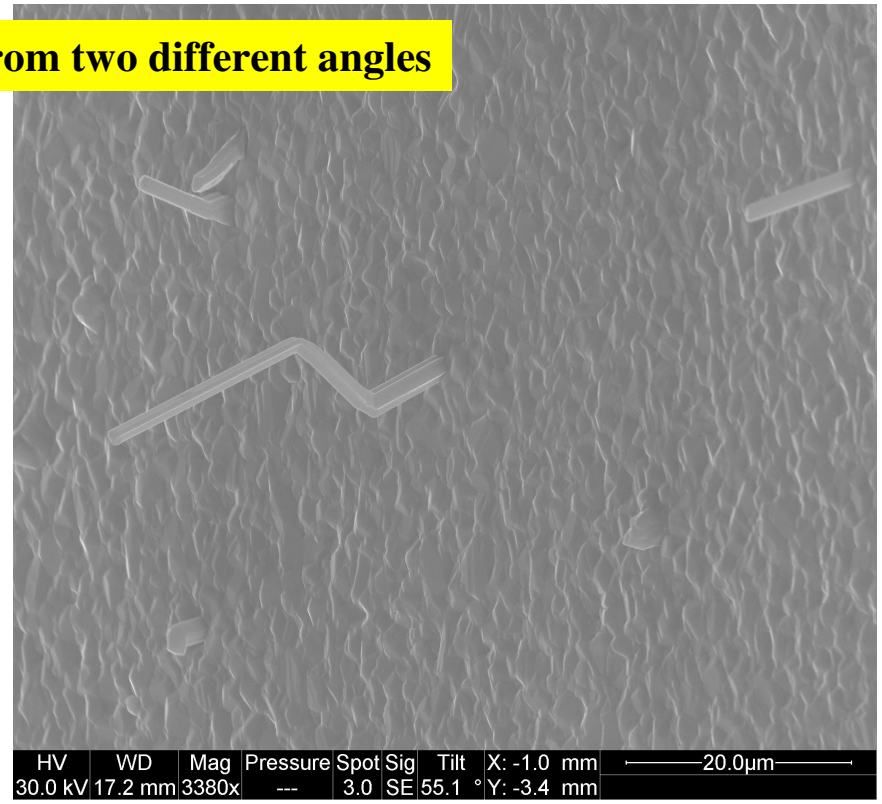




3D Nature of Whiskers

Same whisker viewed from two different angles

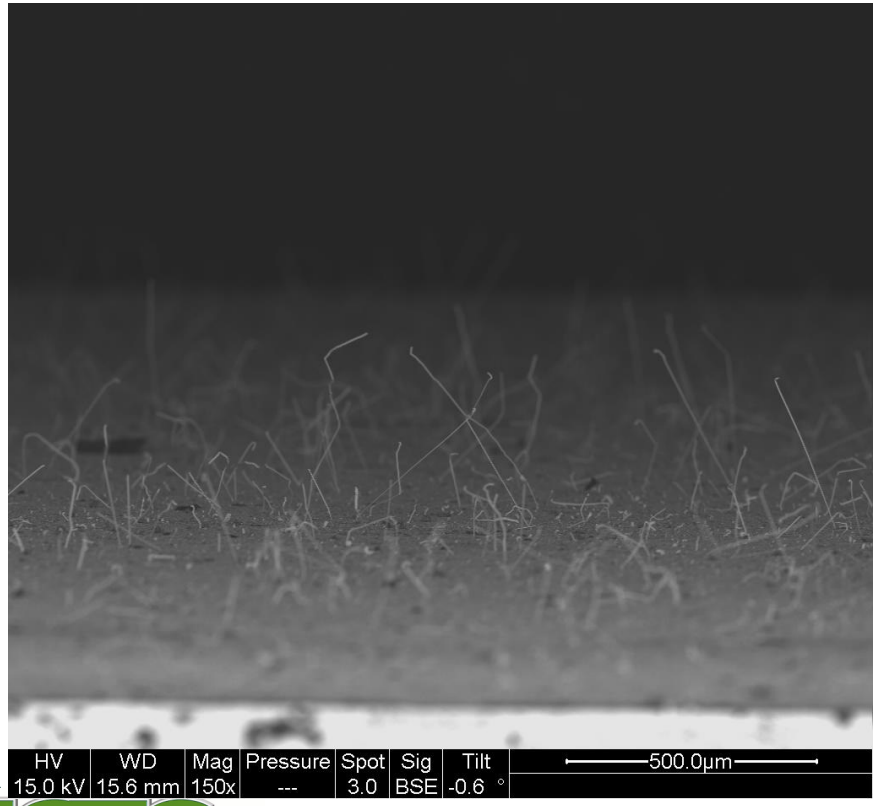


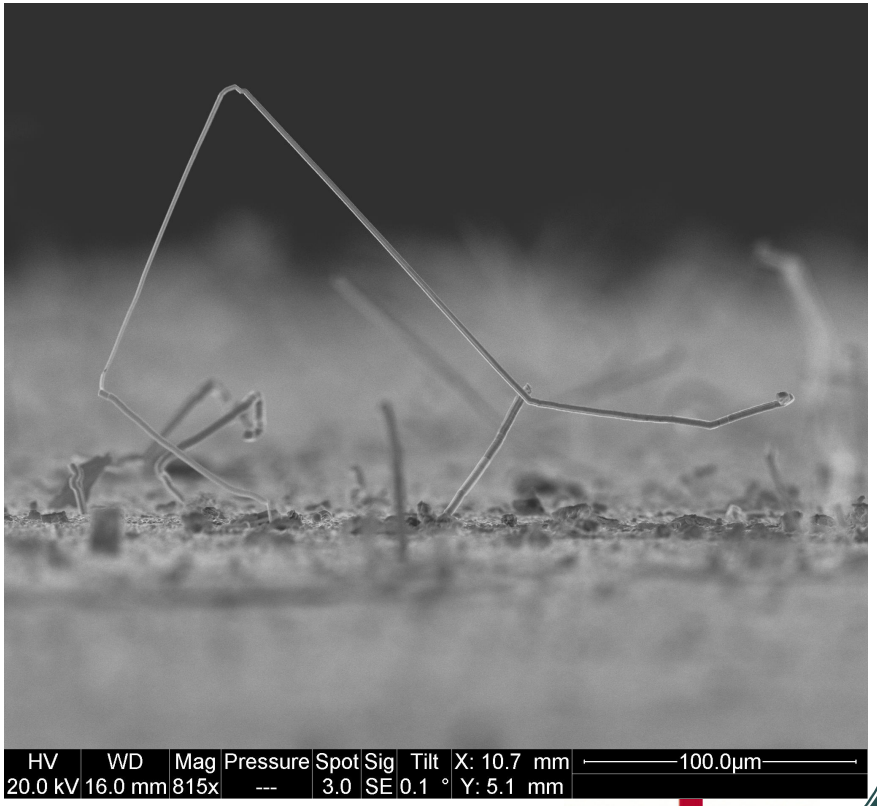


Guidance provided by JESD22-A121 in measurement technique: "… the system must have a stage that is able to move in three dimensions and rotate, such that whisker can be positioned perpendicular to the viewing direction for measurement"

Practicality Issue

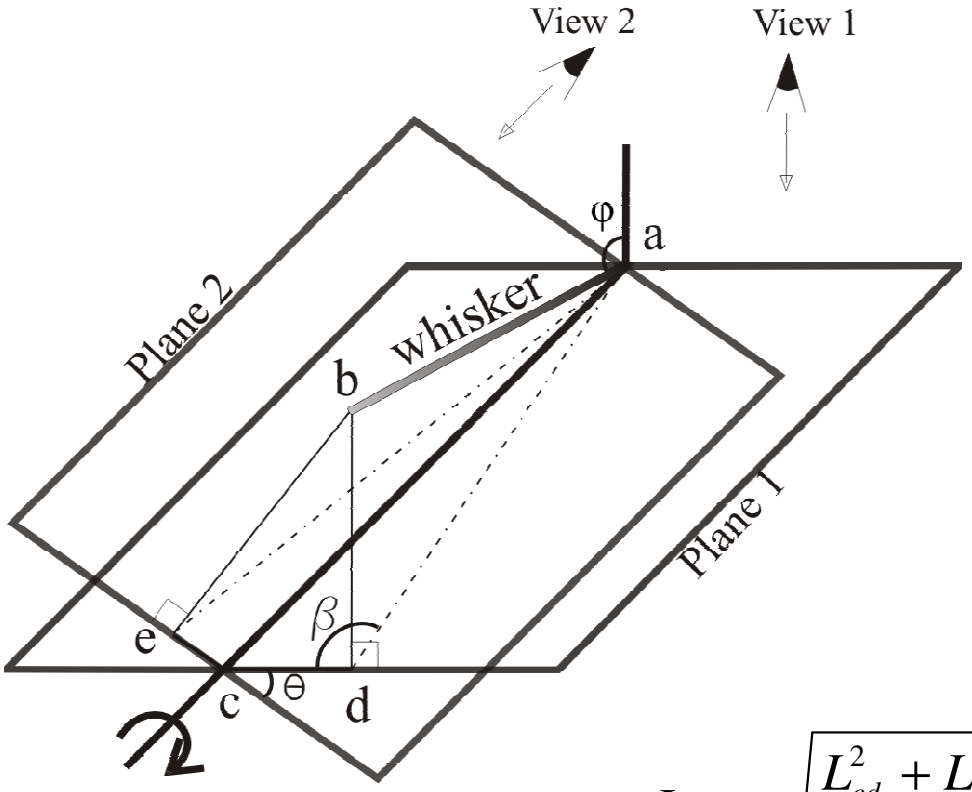
- Too many whiskers to be tilting each one
- Some whiskers exhibit complicated geometries
- Geometry of sample may not allow much degree of freedom
- Nevertheless, any modeling of whisker length requires a statistically significant number of whiskers to be measured. Thus, a more practical approach is needed.





Recommended Length Measurement

A more accurate measurement can be made by using two images offset by a known tilt



Axis along L_{ac} is the tilt axis

L_{cd} = projection of whisker length on axis perpendicular to tilt axis in Plane 1

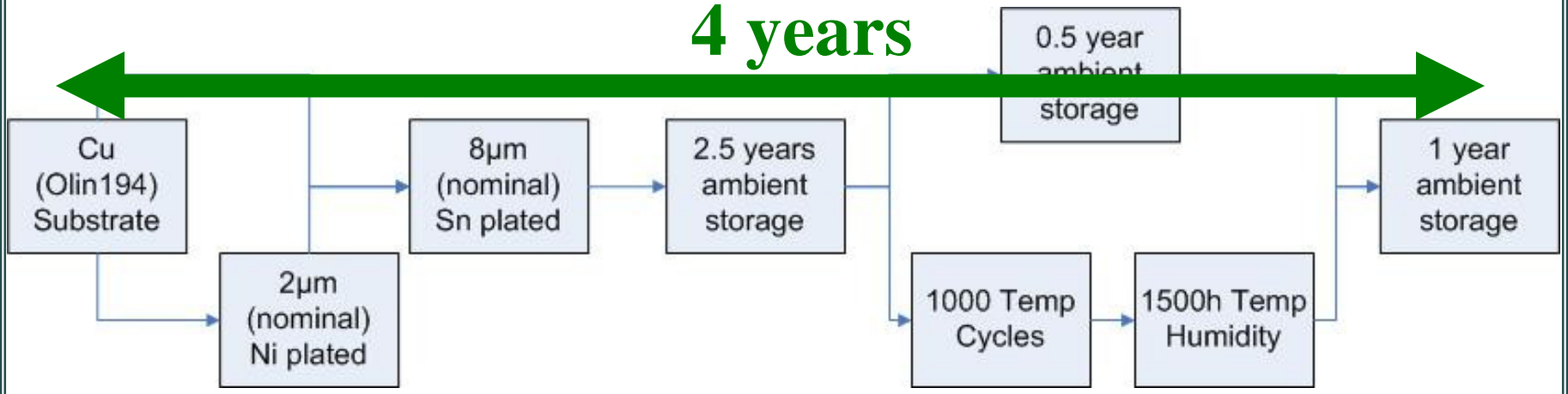
L_{ce} = projection of whisker length on axis perpendicular to tilt axis in Plane 2

θ = tilt angle between Plane 1 and Plane 2

β = angle between L_{cd} and L_{ad} in Plane 1

$$L_{ab} = \sqrt{\frac{L_{cd}^2 + L_{ce}^2 - 2L_{cd}L_{ce}\cos\theta}{\sin^2\theta} + (L_{cd}\tan\beta)^2}$$

Test Description



- 16 commercially electroplated Cu (Olin 194) samples (32mm x 13mm x 0.5mm)
- 8 with 2µm Ni underlayer, 8 without – 12 samples went into testing, 4 samples remained as control
- Sn electroplated to nominal 8µm
- Sn surface grain sizes 2-5µm
- Temp Cycling: -55°C to +85°C, 10min dwells, 3 cycles/hr
- Temp Humidity: +60°C, 87%RH

Test Results: Whisker Length and Density

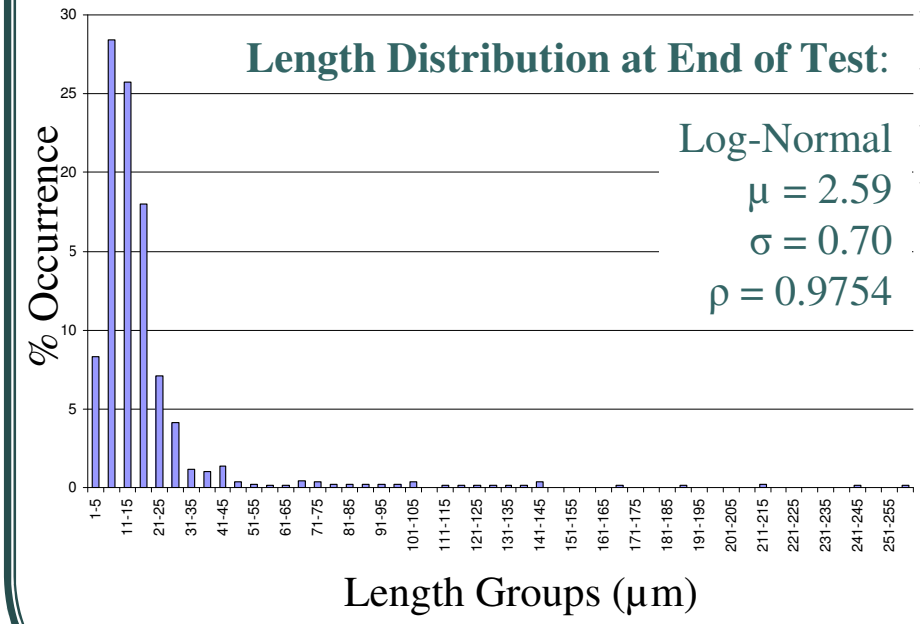
average ± STD

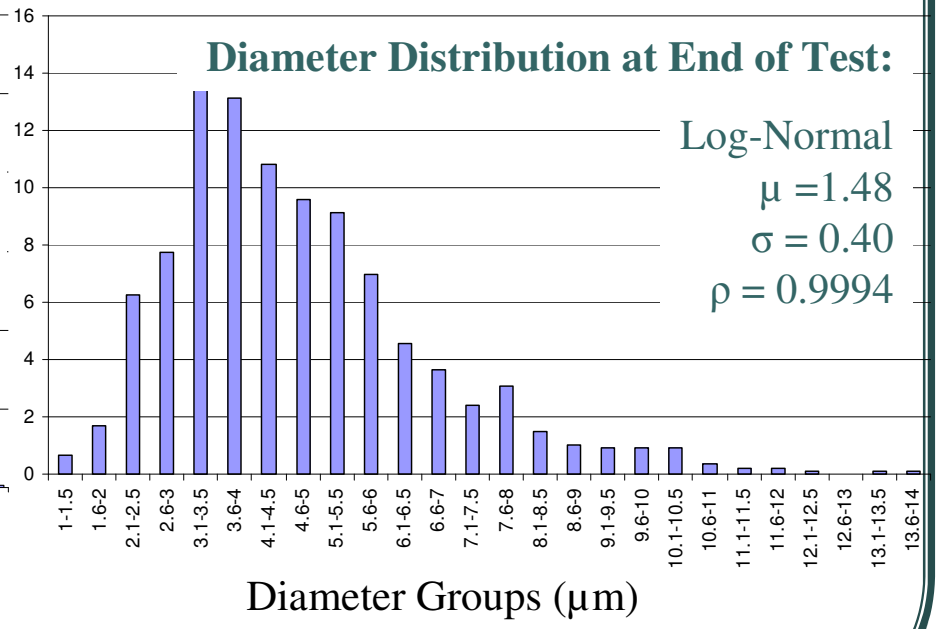
Storage Condition	Measured Parameters	Ni underlayer	No Ni underlayer
2.5 years in Ambient	No whiskers		
Temp Cycling 1000 cycles	Density (#/mm^2)	1907 ± 1524	3216 ± 955
	Avg Length (µm)	12 ± 7	12 ± 6
	Max Length (µm)	51	31
Elevated Temp Humidity 60C/85%RH 2 months	Density (#/mm^2)	1864 ± 1481	2987 ± 1000
	Avg Length (µm)	19 ± 18	12 ± 7
	Max Length (µm)	256	39
Additional 1 year in Ambient	No change since Elevated Temp Humidity		

Ambient-stored control samples grew no whiskers during the 4-year test time

Whisker Length and Diameter Distributions

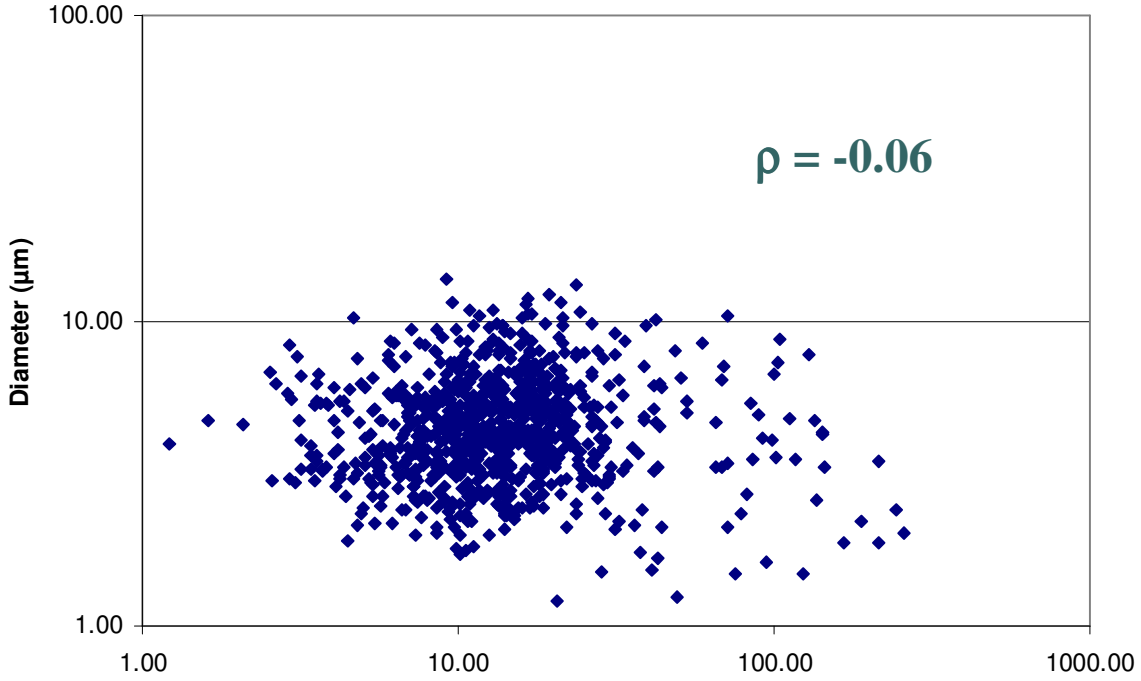
- Data for 877 whiskers from all the coupons collected at the end of the test to see distribution of length and diameter – both follow Log-Normal distributions
- Log-Normal distributions for whisker lengths also at every evaluation point (after 500 and 1000 temperature cycles), for both Ni and no-Ni underlayer samples





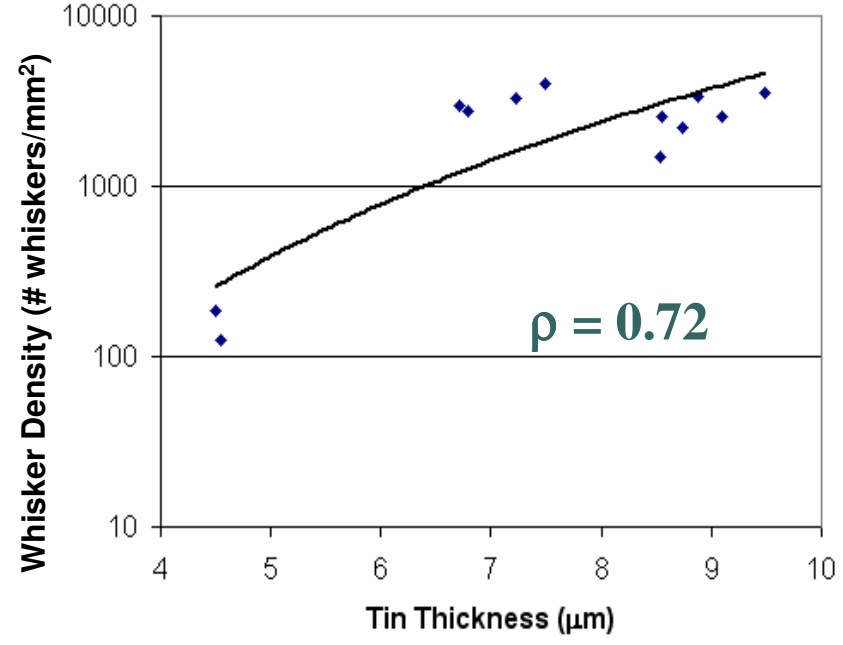
Growth Correlation: Length vs Diameter

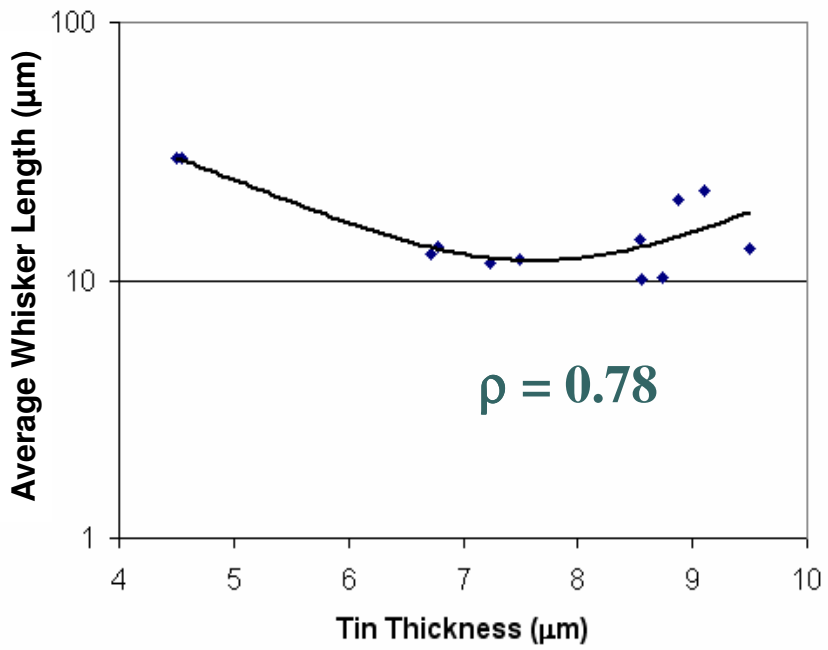
- Are longer whiskers generally thinner, while large-diameter whiskers stay shorter?
  - Tin atoms diffuse across long ranges to make up the whisker. Possibly the amount of tin in each whisker is similar
- NO CORRELATION found (correlation coefficient -0.06) between whisker length and diameter
- Attempts made to see if correlation would exist, if data is separated into subgroups, NO CORRELATION found in any of the cases



Whisker Density and Length vs Plating Thickness

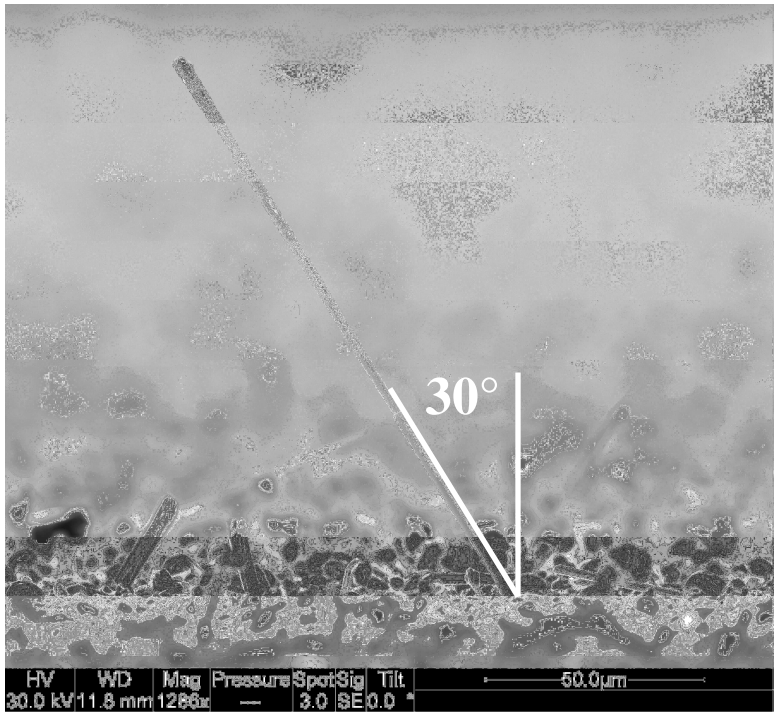
- Thickness measured using X-Ray Fluorescence (XRF)
- For the 12 samples (6 with Ni, 6 without Ni underlayer) used in environmental testing, tin plating thickness varied from 4.5 to 9.5µm
- Ni underlayer thickness ranged from 1.2 to 1.5µm
- Analysis of data indicates that both whisker density and lengths are related to tin thickness

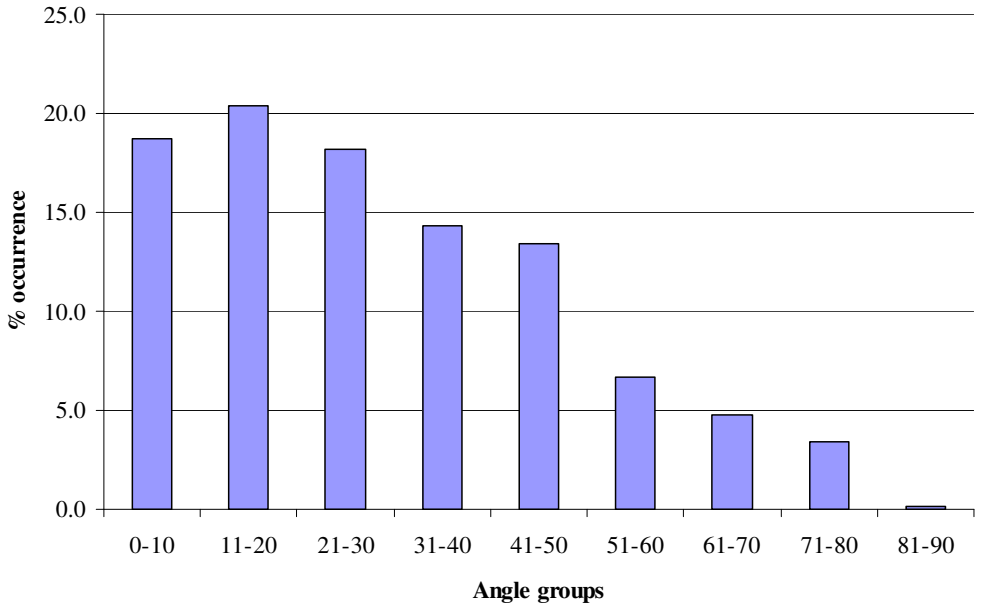




Whisker Growth Angle

- Growth angle measured between whisker and axis normal to surface
- No preferential growth angle seems to exist, but whiskers are less prone growing close to the surface





Note: Although not explicitly evident from this work, whisker growth angle CAN change during its growth period

Conclusions

- Measurement of whisker length using two images separated by a known tilt angle provides a consistent and relatively straight forward method of estimating whisker length and provides an improvement to JEDEC recommended method
- For tested tin finish, sequential temperature cycling and elevated temperature and humidity was effective at producing whisker growth
- Environmental tests provided no acceleration as compared to room-ambient growth, but instead – induced growth
- Nickel underlayer was not effective in preventing tin whisker growth
- Whisker lengths and diameters follow log-normal distribution, and have no correlation between each other
- For tested tin finish, whisker density found to increase with plating thickness
- For tested tin finish, whisker length decrease than increase with plating thickness
- No preference in whisker growth angle, but whiskers are less prone to growing parallel to surface