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
  - Whisker Growth 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 (†)**	**ET-7410**
Issue Date	2007/5	2008/7	2005/12
Preconditioning	Soldering simulation Lead Forming	Reflow Lead Forming	Lead Forming
Ambient Storage	30°C, 60%RH 25°C, 55%RH 4000 hrs	30°C, 60%RH	30°C, 60%RH 4000 hrs
Elevated Temperature Humidity Storage	55°C, 85%RH 2000 hrs	55°C, 85%RH 60°C, 87%RH (*)	55°C, 85%RH 2000 hrs
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	-40°C to 85°C 1000 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)

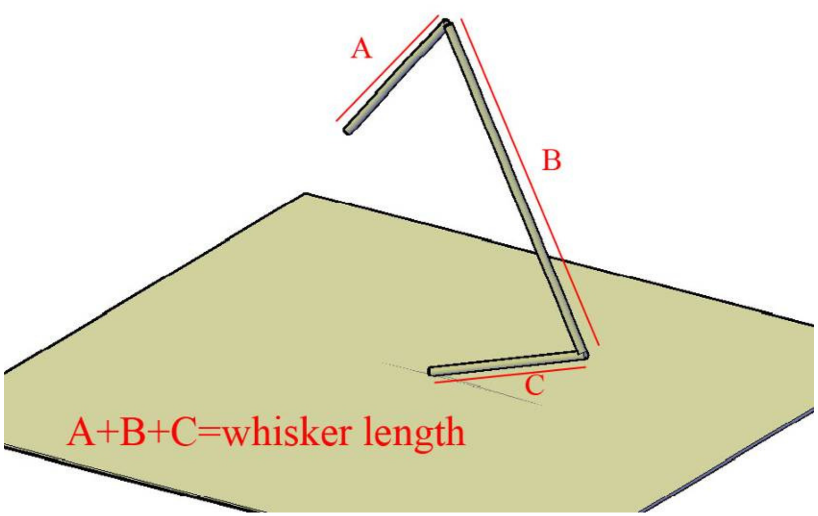
The distance between the finish surface and the tip of the whisker that would exist if the whisker were straight and perpendicular to the surface

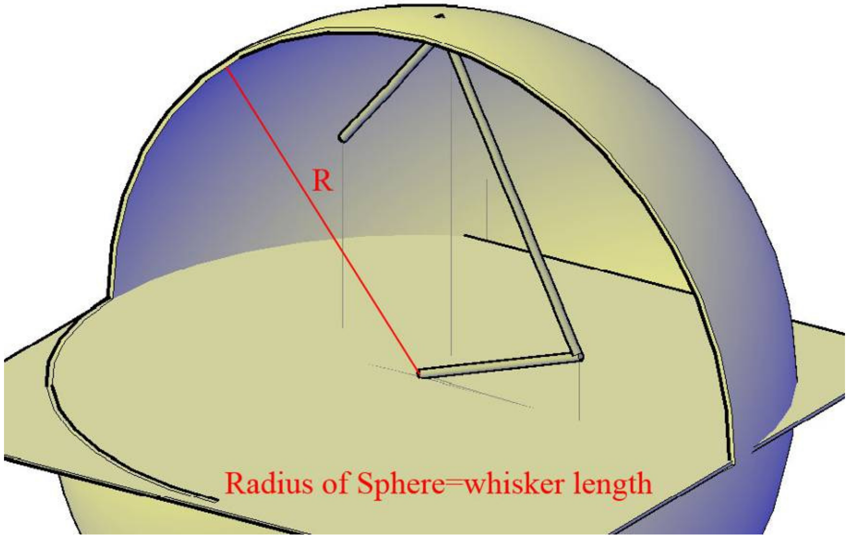
JESD201 (March 2006)

JESD22-A121A (July 2008)

IEC 60068-2-82 (May 2007)

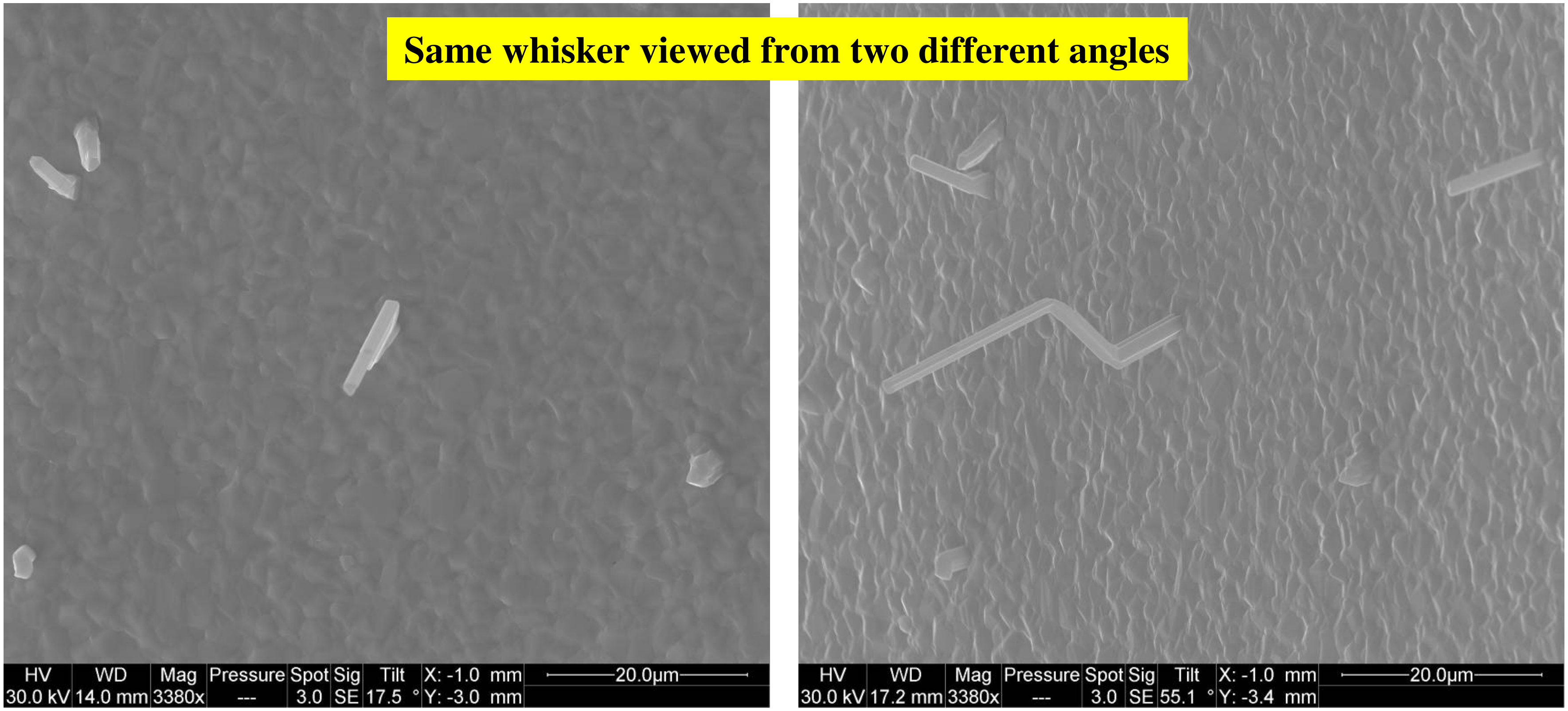
The straight line distance from the point of emergence of the whisker to the most distant point on the whisker





This method was used in current research

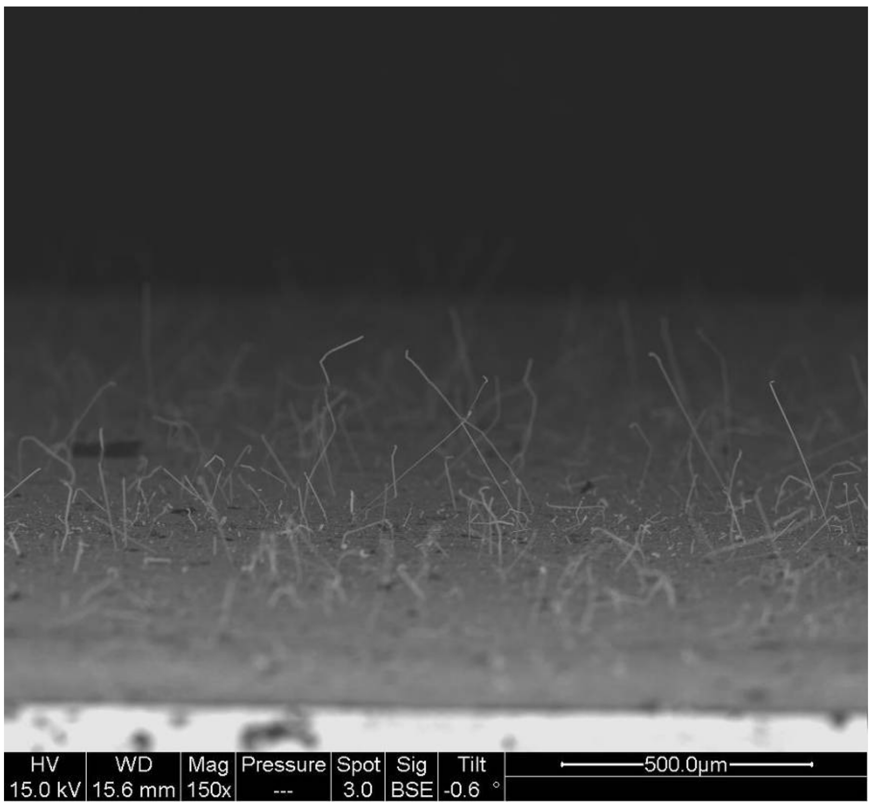
3D Nature of Whiskers

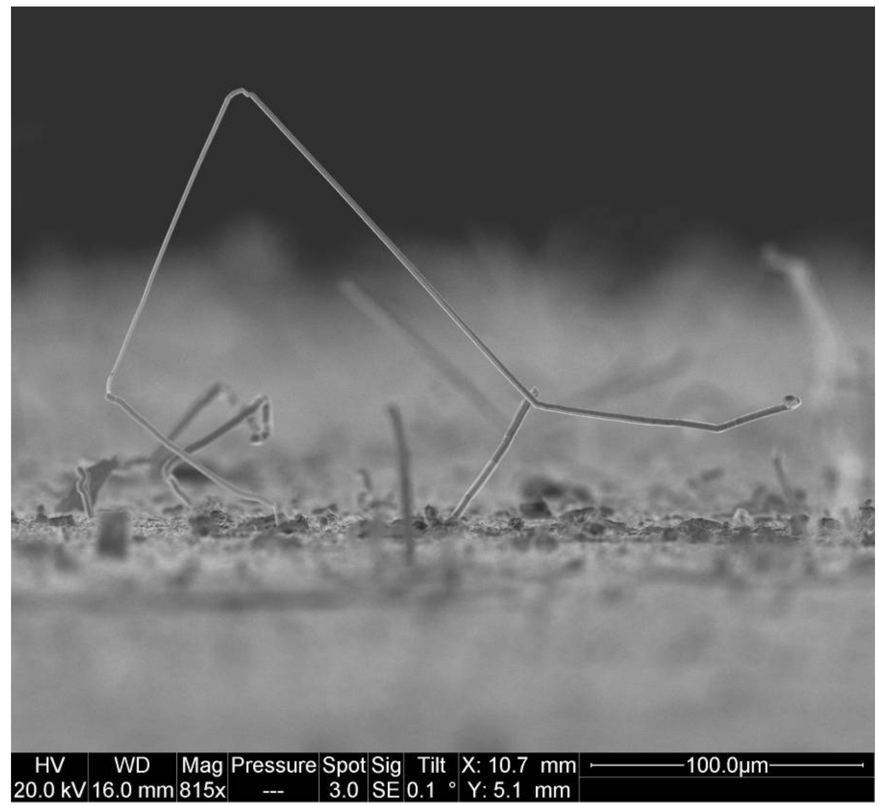


Guidance provided by JESD22-A121 in measurement technique: "… the system must have a stage that is able to move in three dimensions and rotate, such that whisker can be positioned perpendicular to the viewing direction for measurement"

Practicality Issue

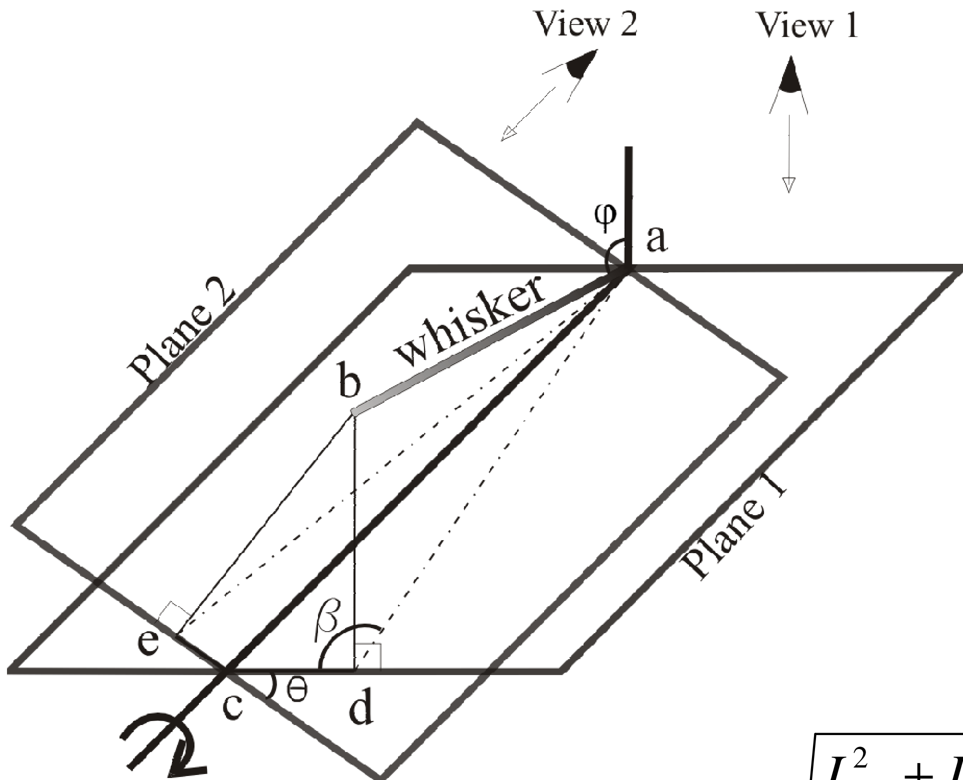
- Too many whiskers to be tilting each one
- Some whiskers exhibit complicated geometries
- Geometry of sample may not allow much degree of freedom
- Nevertheless, any modeling of whisker length requires a statistically significant number of whiskers to be measured. Thus, a <u>more practical approach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





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

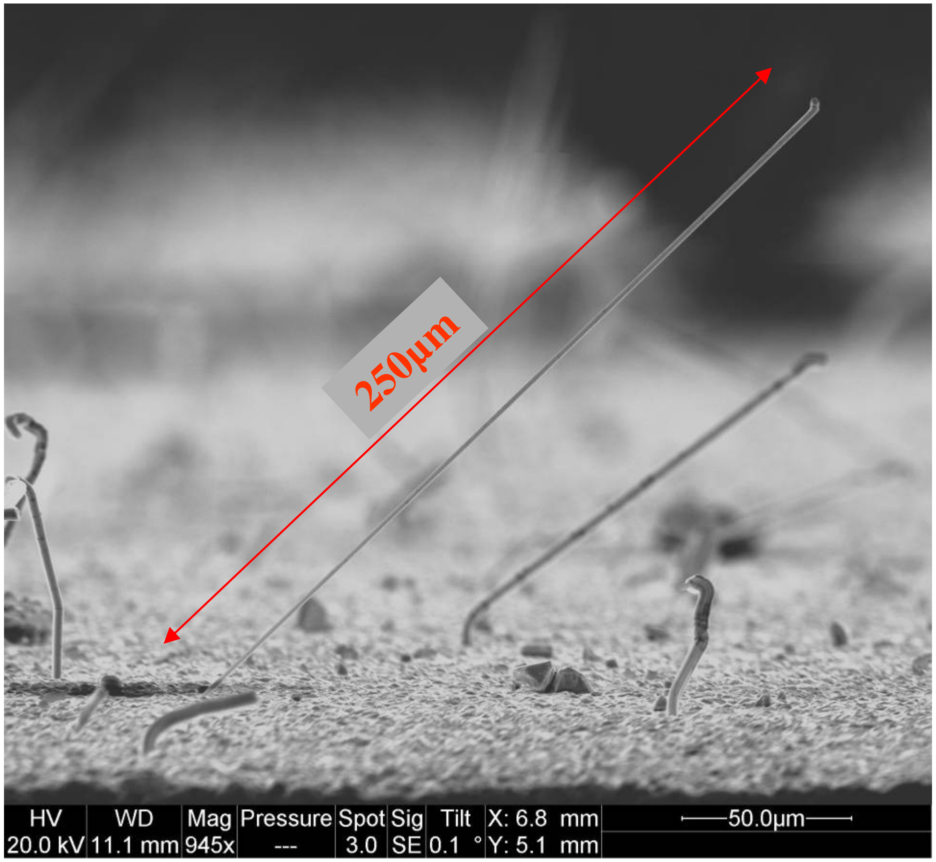
L_{ce} = projection of whisker length on axis perpendicular to tilt axis in Plane 2

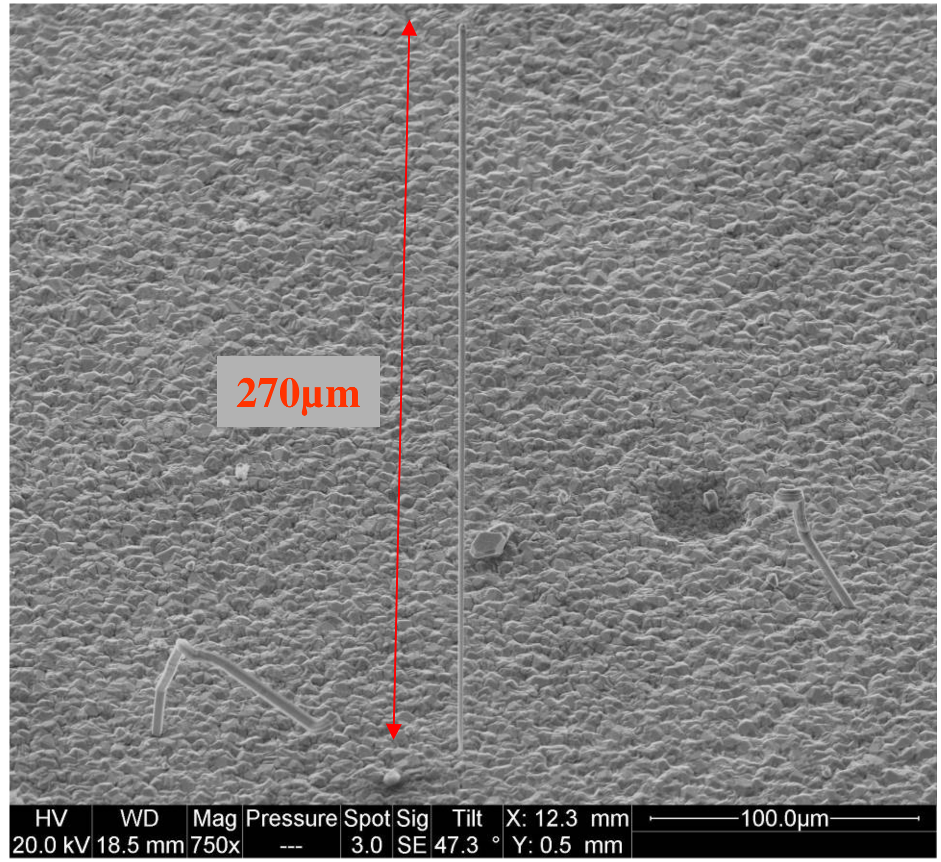
θ = tilt angle between Plane 1 and Plane 2

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

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

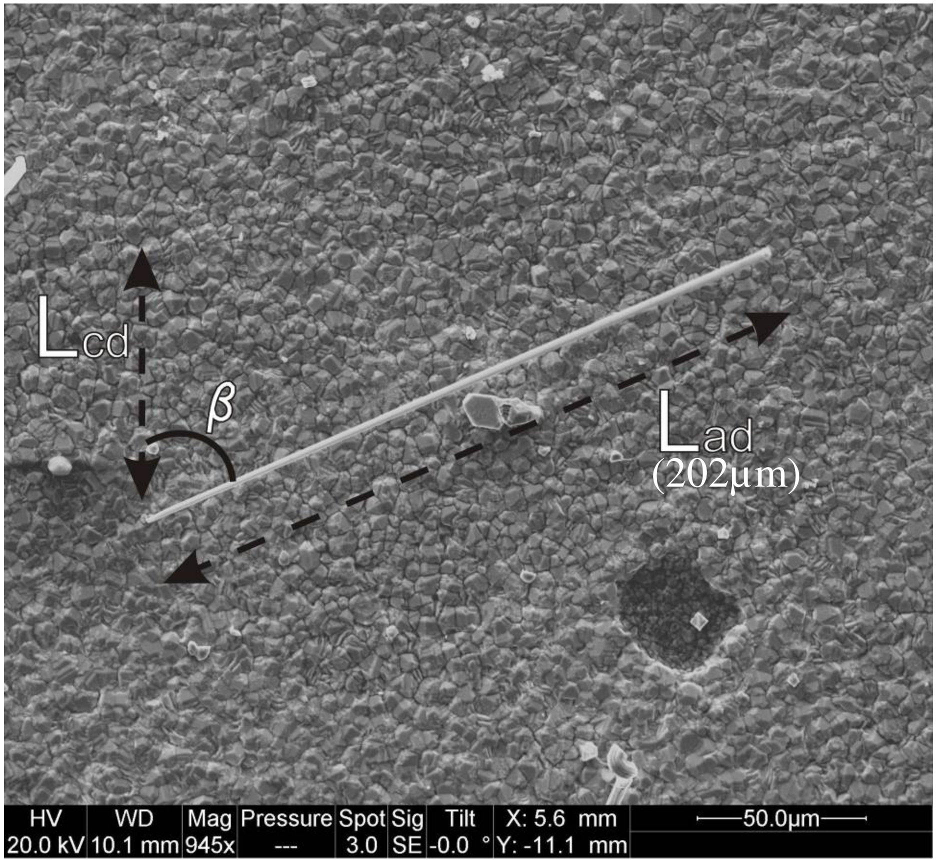
Finding Whisker Length – the Painful Way

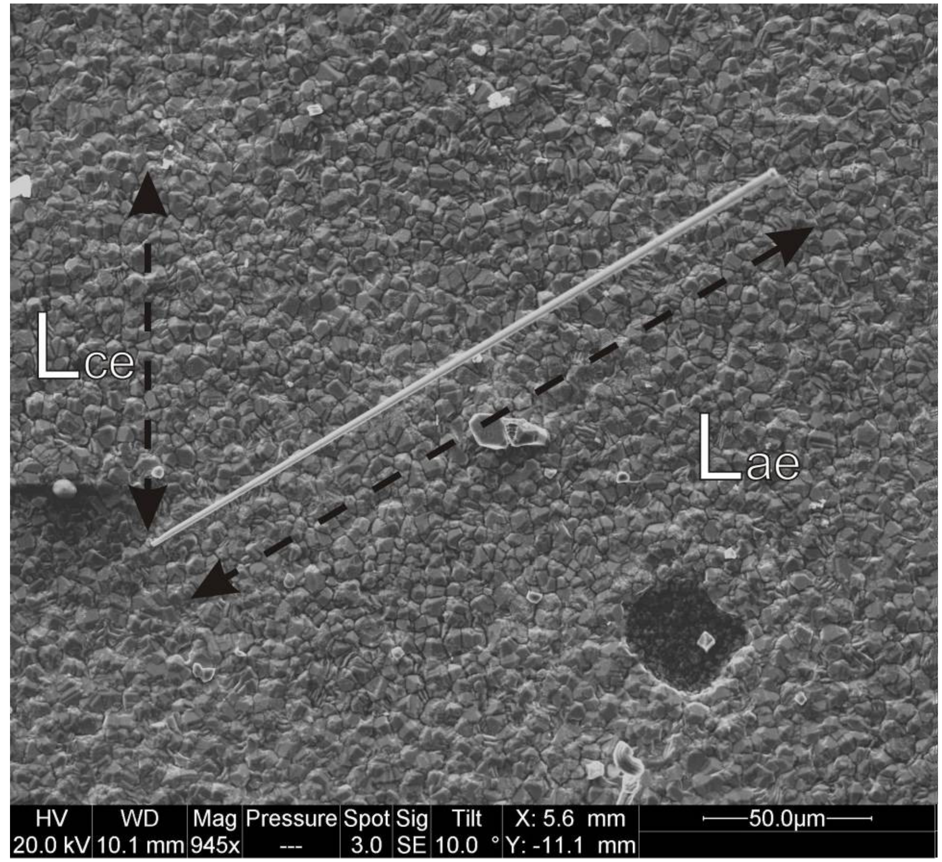




In order to find the length of this whisker, sample had to be first rotated and significantly tilted, as suggested by JESD22-A121 – a time consuming process

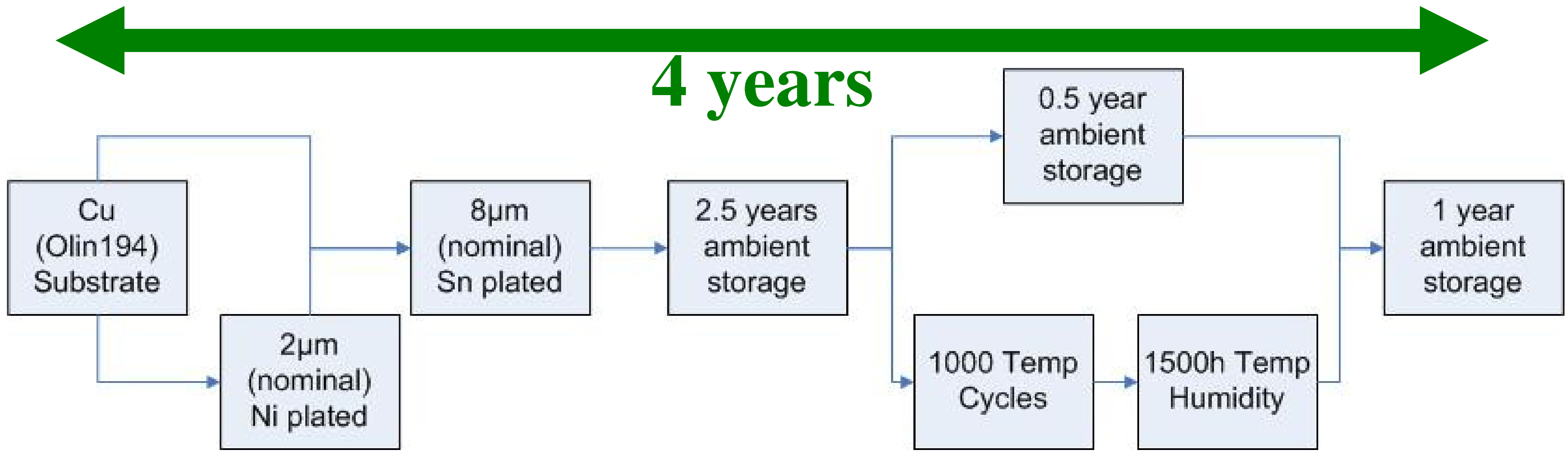
Finding Whisker Length – the Recommended Way





- L_{cd} = 79µm; L_{ce} = 109µm; $\beta = 67°$; $\theta = 10°$ - a tilt of 10° is sufficient
- True Length 270µm (same as recorded after rotating/tilting whisker to position perpendicular to view)

Test and Sample 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

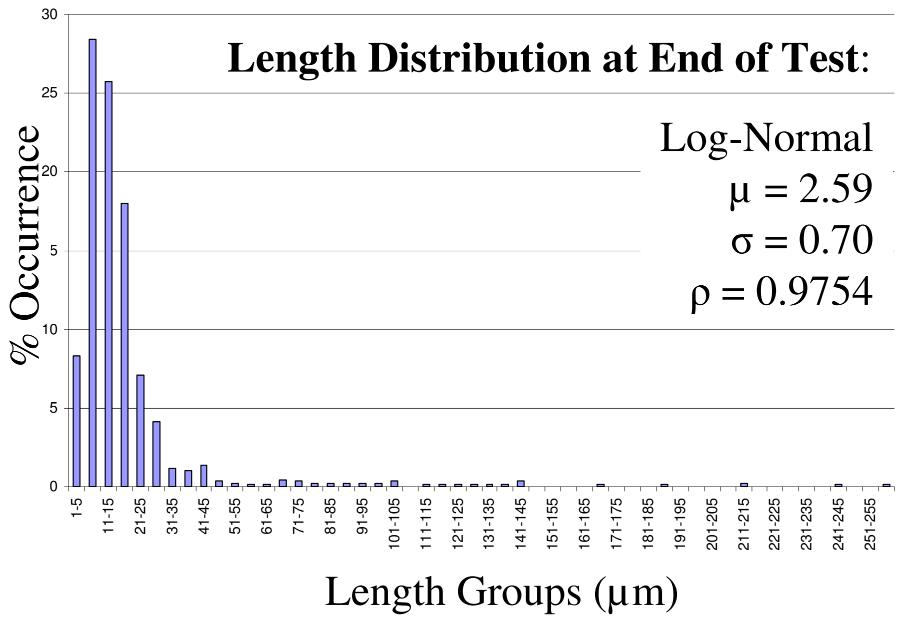
average ± STD

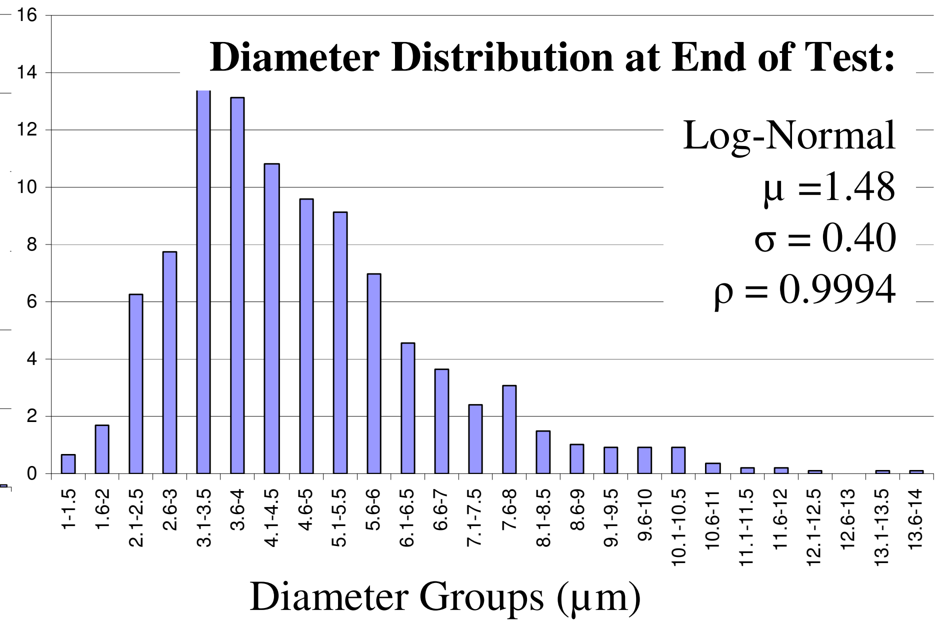
Storage Condition	Measured Parameters	Ni underlayer	No Ni underlayer
2.5 years in Ambient	No whiskers		
Temp Cycling 1000 cycles	Density (#/mm^2)	1907 ± 1524	3216 ± 955
	Avg Length (µm)	12 ± 7	12 ± 6
	Max Length (µm)	51	31
Elevated Temp Humidity 60C/85%RH 2 months	Density (#/mm^2)	1864 ± 1481	2987 ±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

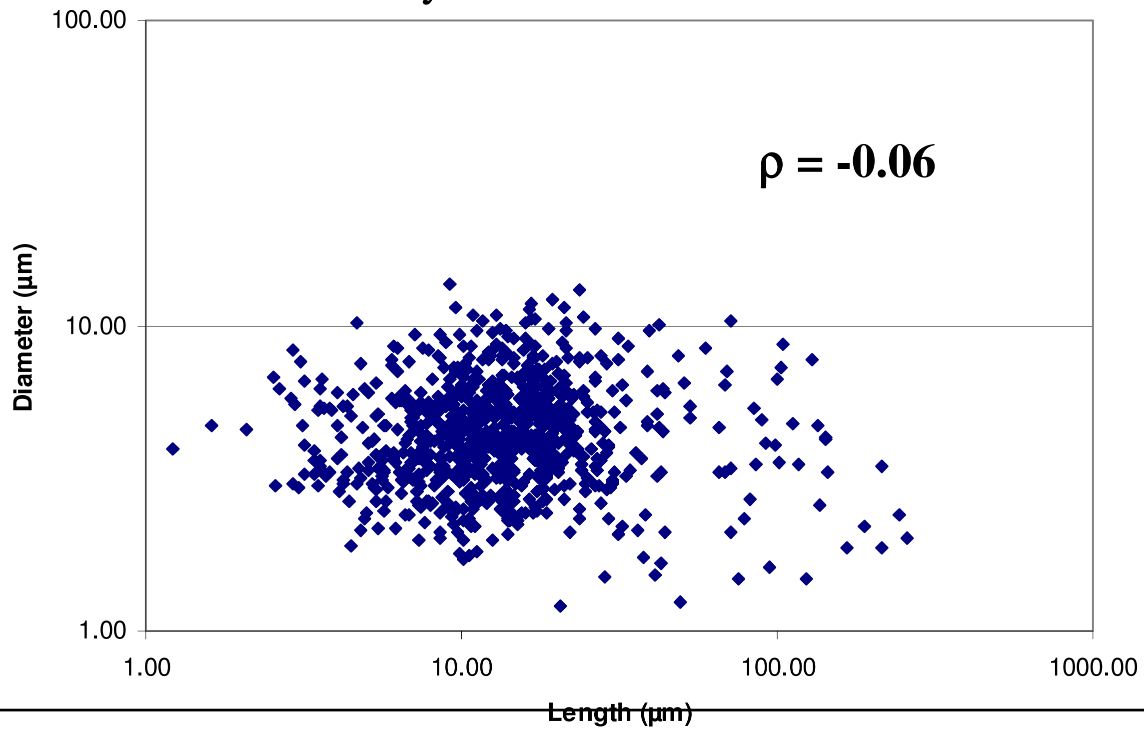
- Data for 877 whiskers from all the coupons collected at the end of the test to see distribution of length and diameter – both follow Log-Normal distributions
- Log-Normal distributions for whisker lengths also at every evaluation point (after 500 and 1000 temperature cycles), for both Ni and no-Ni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





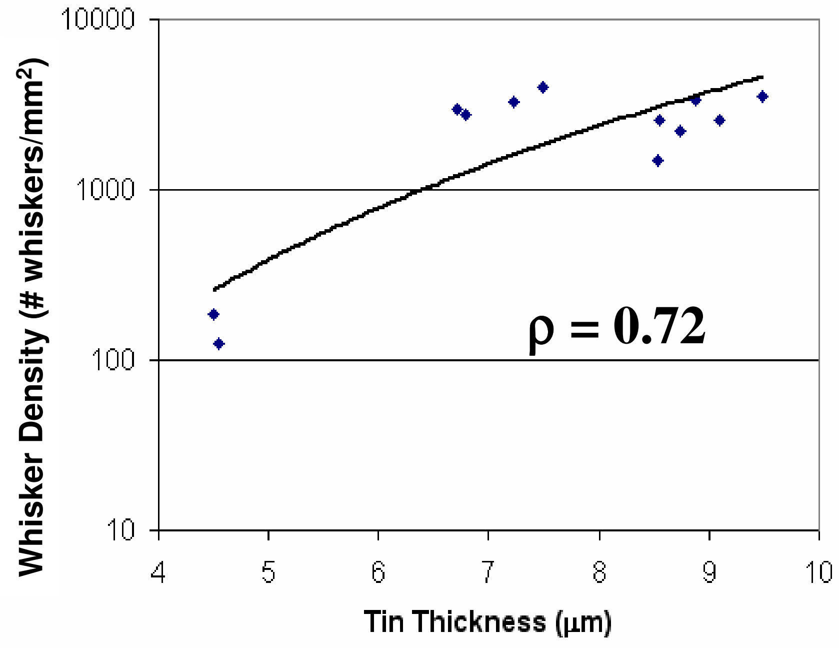
Growth Correlation: Length vs Diameter

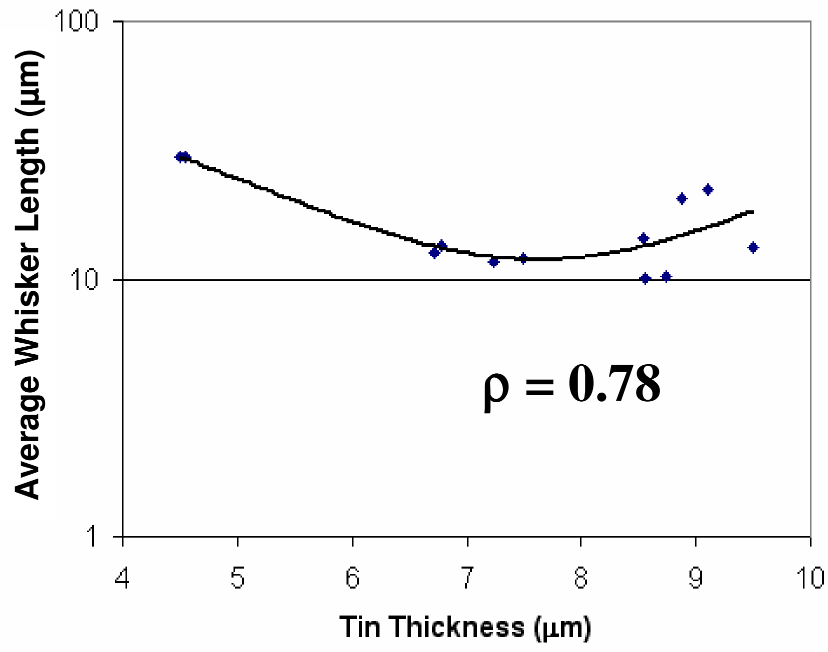
- <u>Are longer whiskers generally thinner, while large-diameter whiskers stay shorter?</u>
  - Tin atoms diffuse across long ranges to make up the whisker. Possibly the amount of tin in each whisker is similar
- NO CORRELATION found (correlation coefficient -0.06) between whisker length and diameter, from data collected at the end of the test
- 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

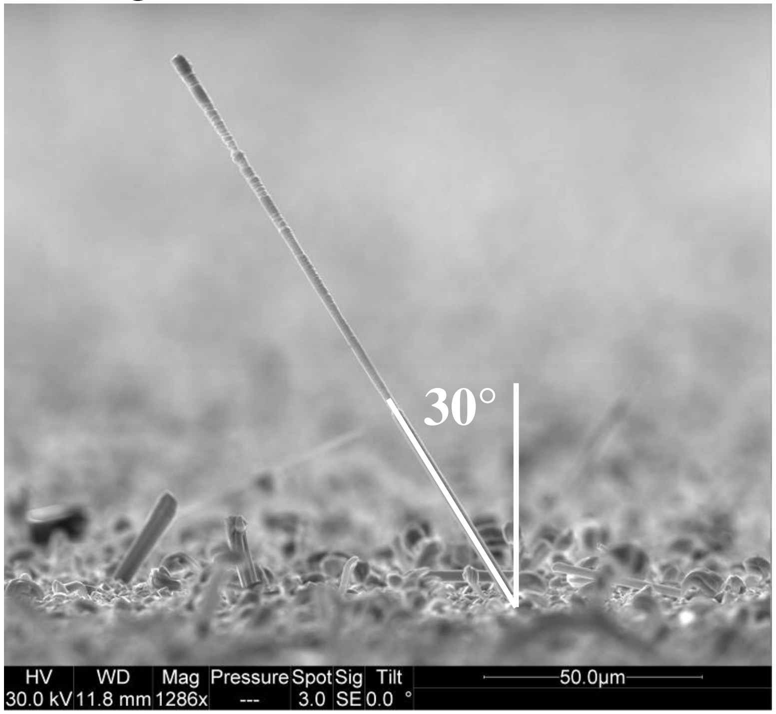
- Thickness measured using X-Ray Fluorescence (XRF)
- For the 12 samples (6 with Ni, 6 without Ni underlayer) used in environmental testing, tin plating thickness varied from 4.5 to 9.5µm
- Ni underlayer thickness ranged from 1.2 to 1.5µm
- Analysis of data indicates that both whisker density and lengths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

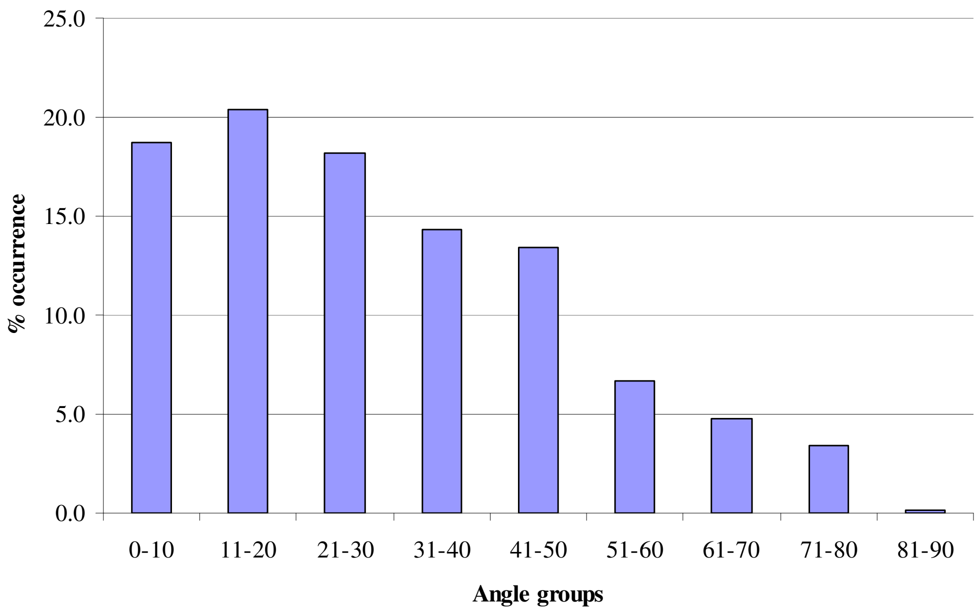




Whisker Growth Angle

- Growth angle measured between whisker and axis normal to surface
- No preferential growth angle seems to exist, but whiskers are less prone to grow close to the surface – same shown by Hilty[1] and Fang[2]

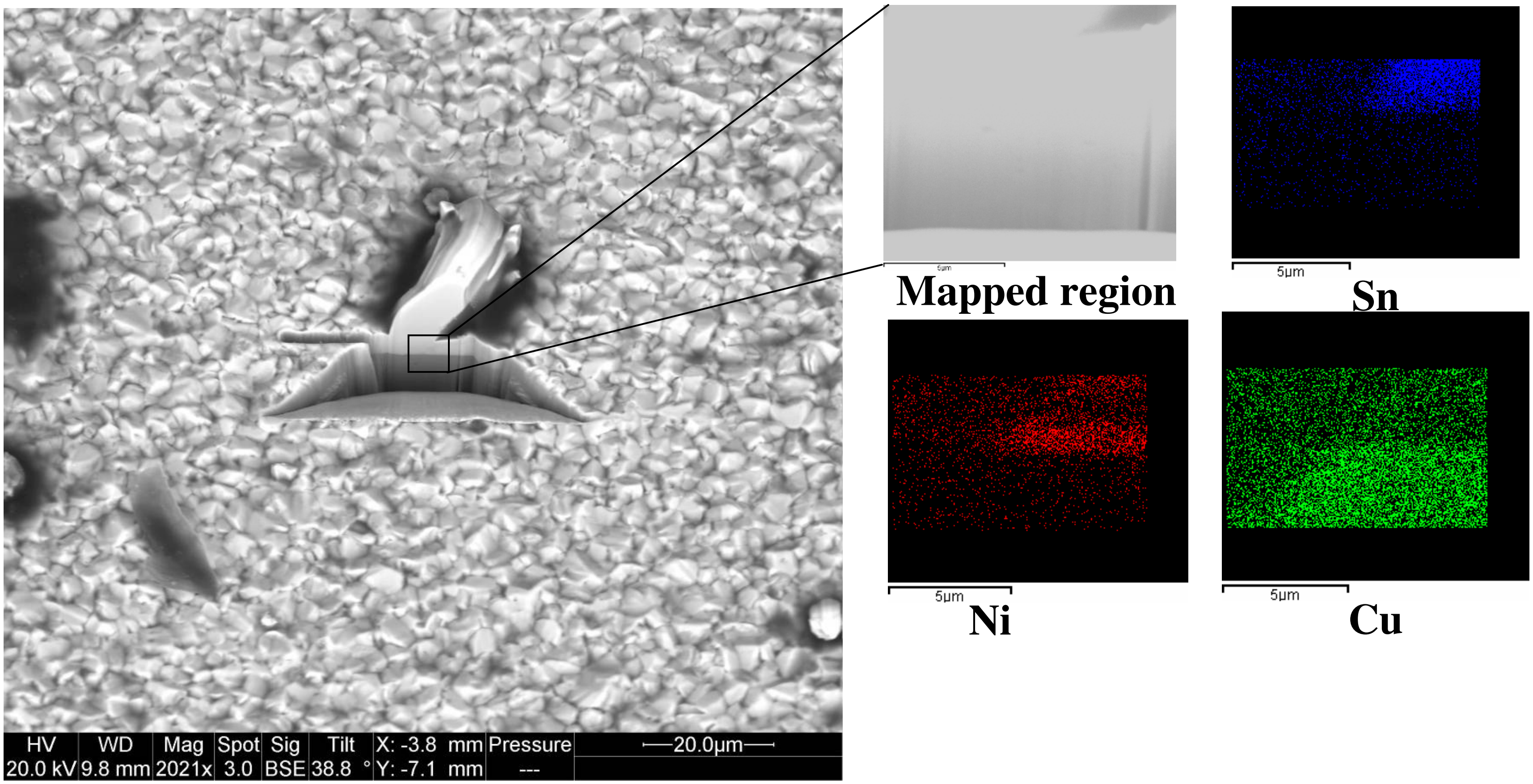




Note: Although not explicitly evident from this work, whisker growth angle CAN change during its growth period
See http://www.calce.umd.edu/tin-whiskers/whiskermovies.htm for examples

[1] R.D. Hilty, N. Corman, "Tin Whisker Reliability Assessment by Monte Carlo Simulation", IPC/JEDEC Lead Free Symposium, San Jose, CA, April 2005
[2] T. Fang, M. Osterman, S. Mathew, M. Pecht, "Tin Whisker Risk Assessment", Circuit World, Vol. 32 No 3, pp. 25-29, 2006

EDS Analysis of a FIB area



EDS analysis found tin, nickel and copper:
Confirms presence of Ni layer

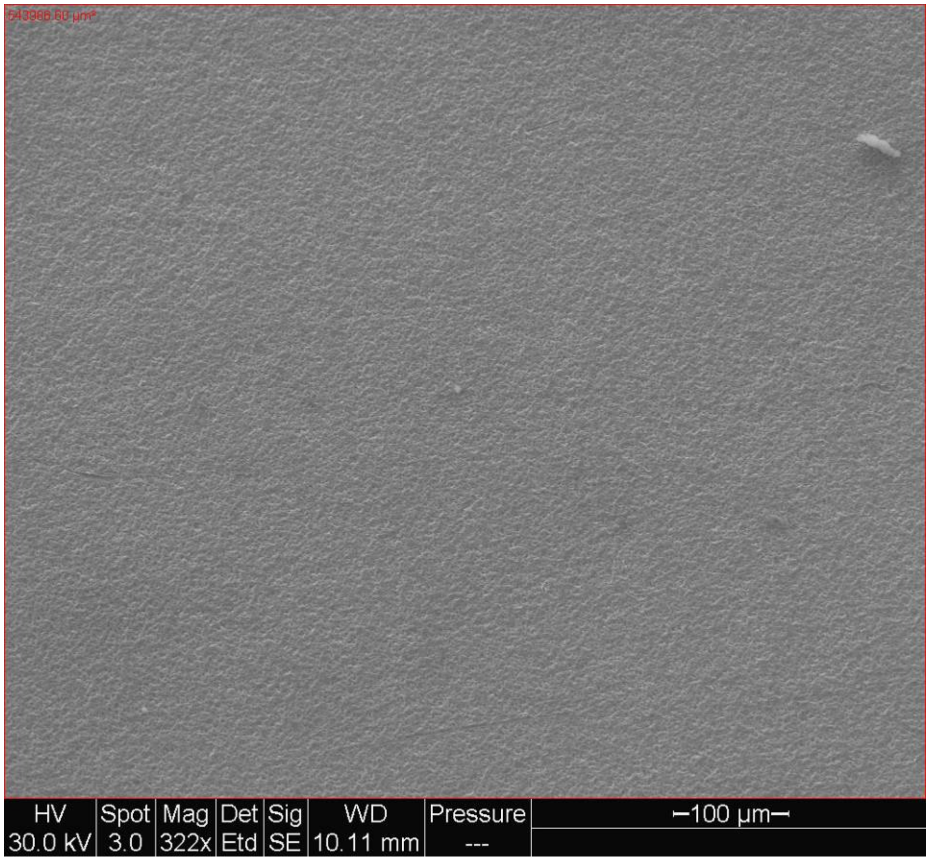
Conclusions

- 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 grow parallel to surface

Back Up – Additional Images

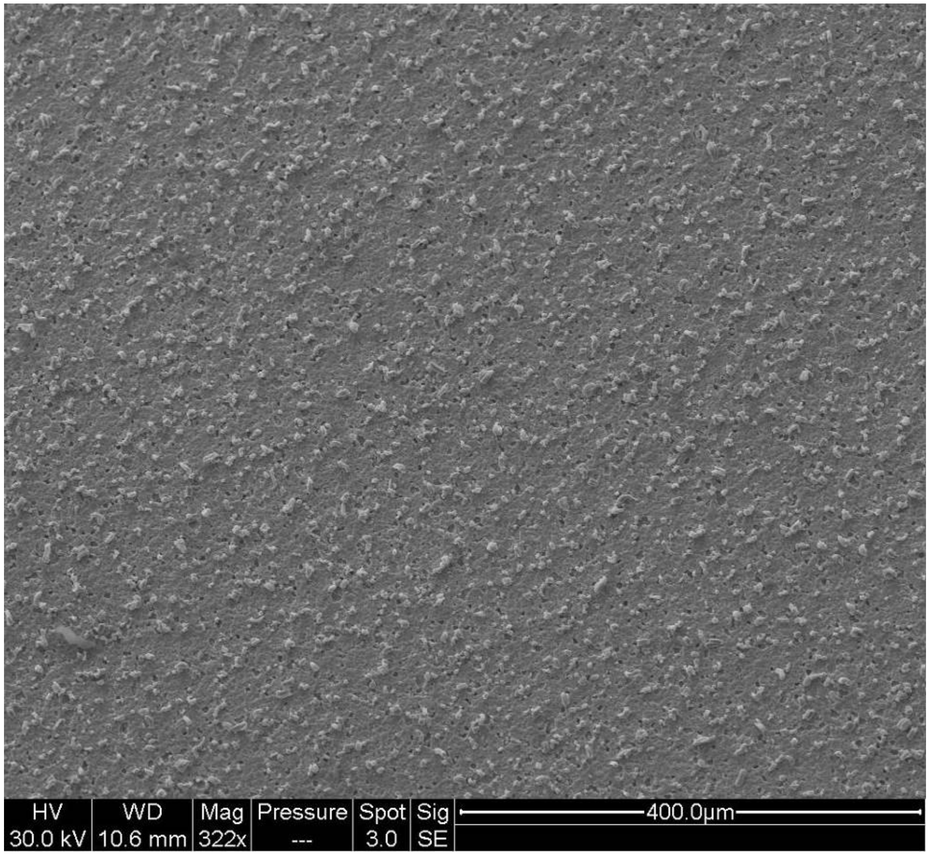
Evolution of Plating: Sn-plated, Ni underlayer, Cu substrate Sample (1/3)

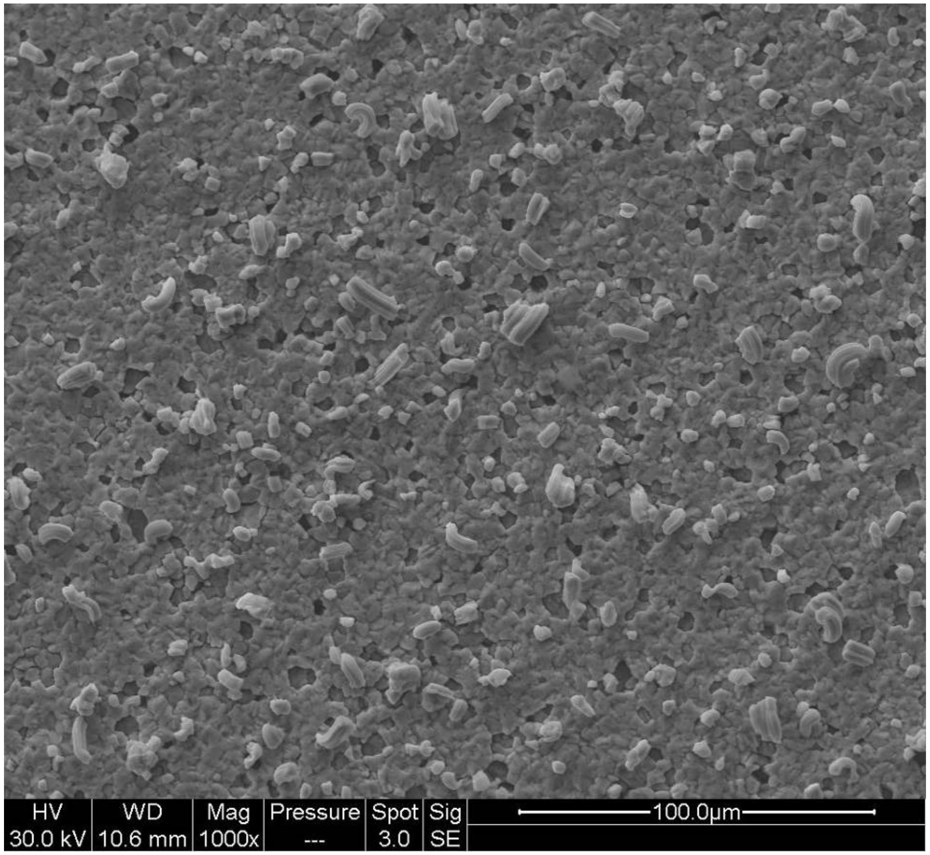
Pre-Test



Evolution of Plating: Sn-plated, Ni underlayer, Cu substrate Sample (2/4)

500 Temperature Cycles

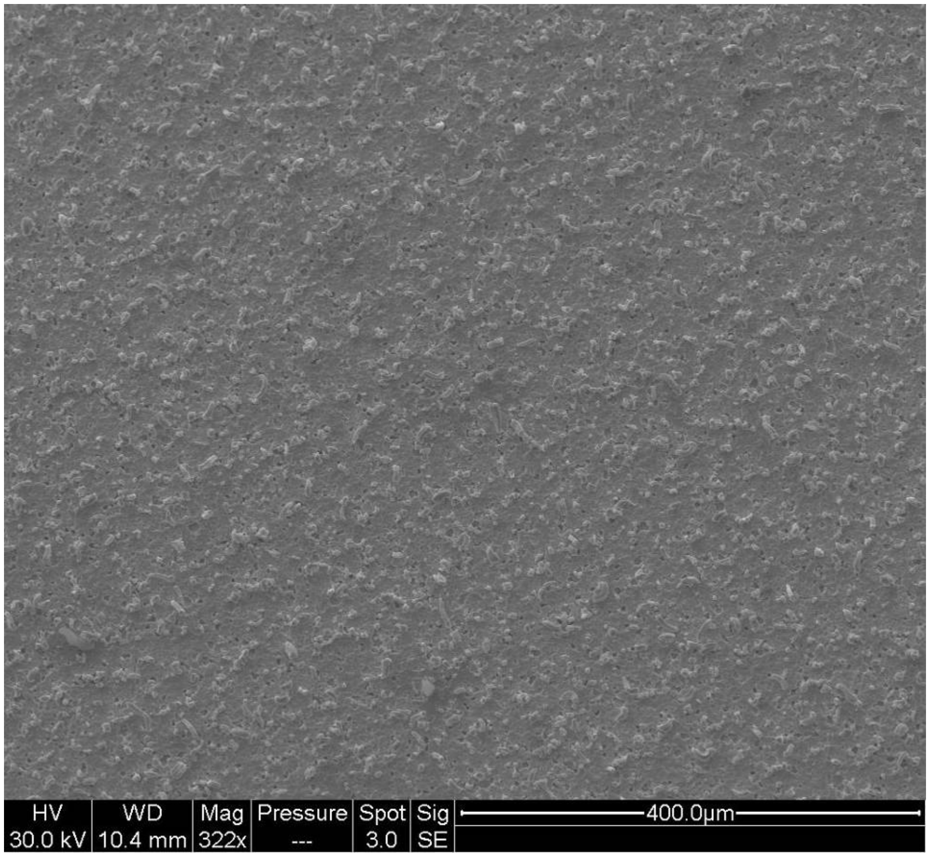


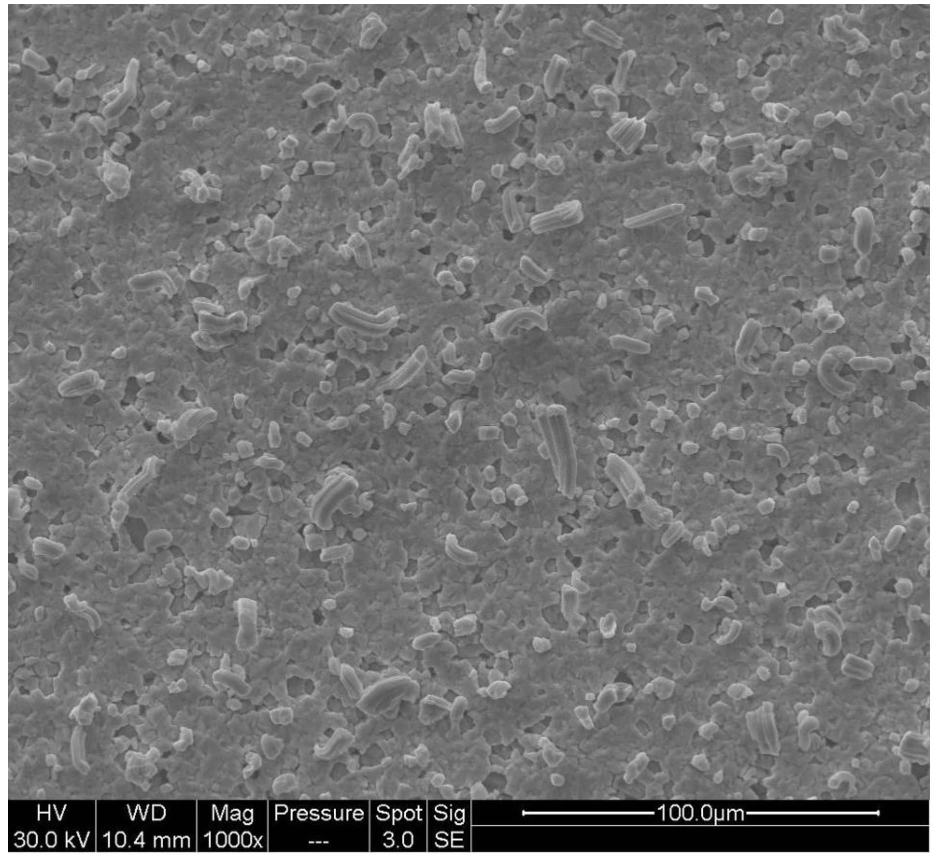


Zoom-In of the picture on left

Evolution of Plating: Sn-plated, Ni underlayer, Cu substrate Sample (3/4)

1000 Temperature Cycles

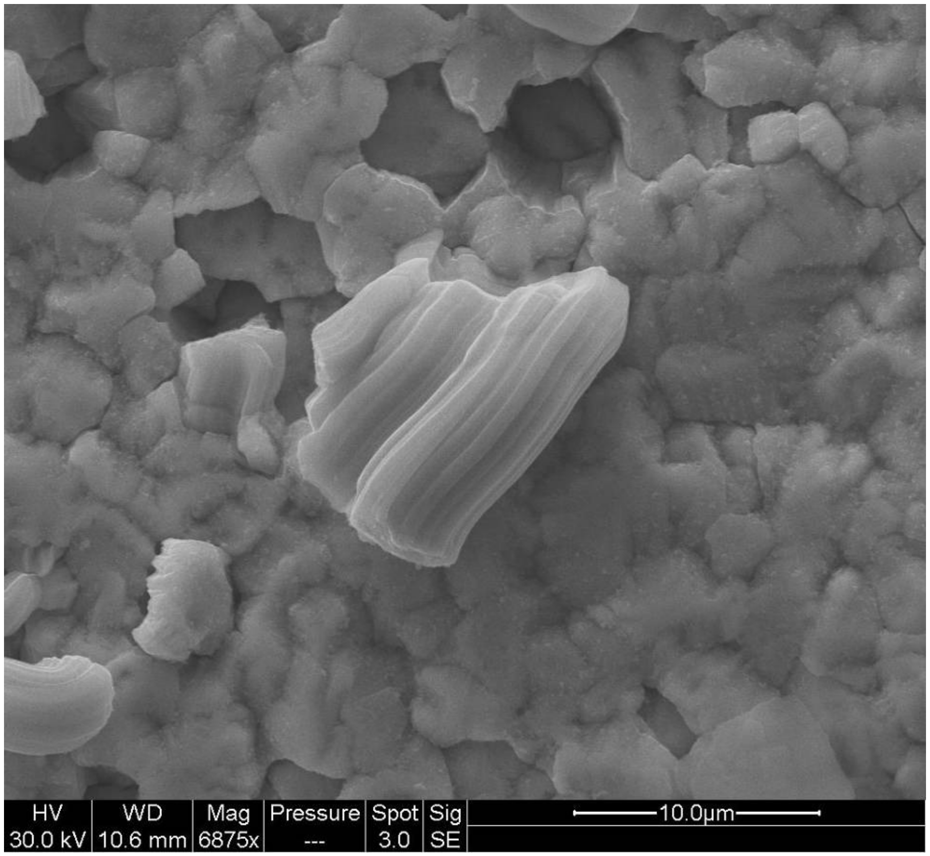




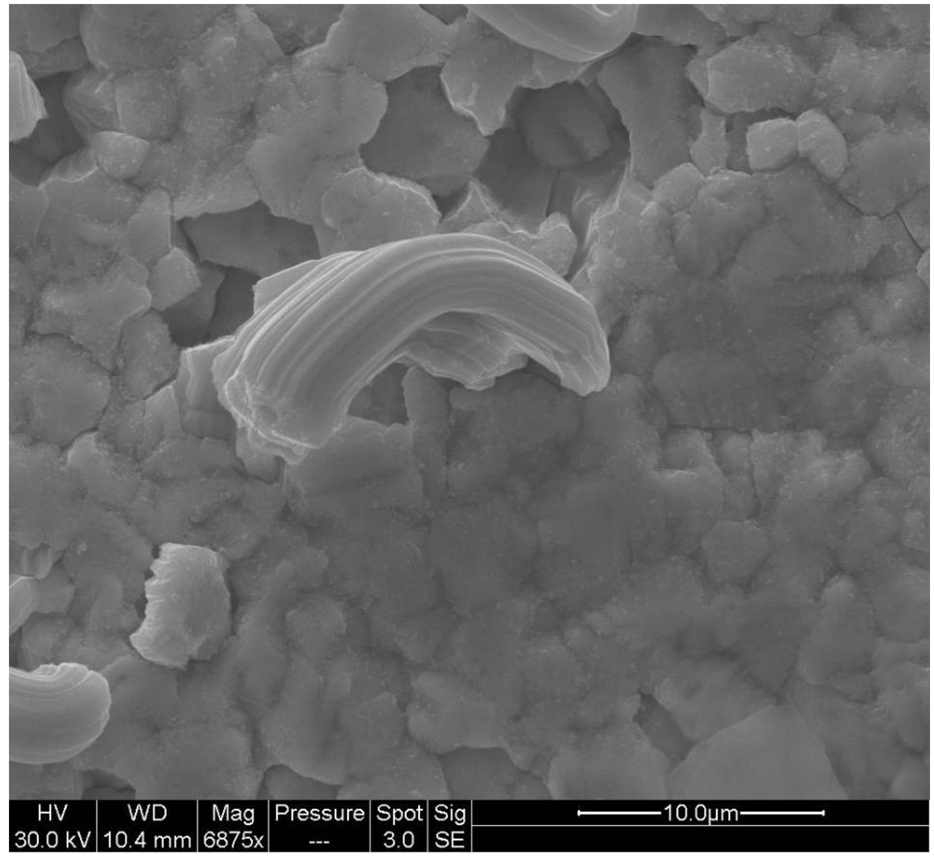
Zoom-In of the picture on left

Evolution of Plating: Sn-plated, Ni underlayer, Cu substrate Sample (4/4)

500 Temperature Cycles

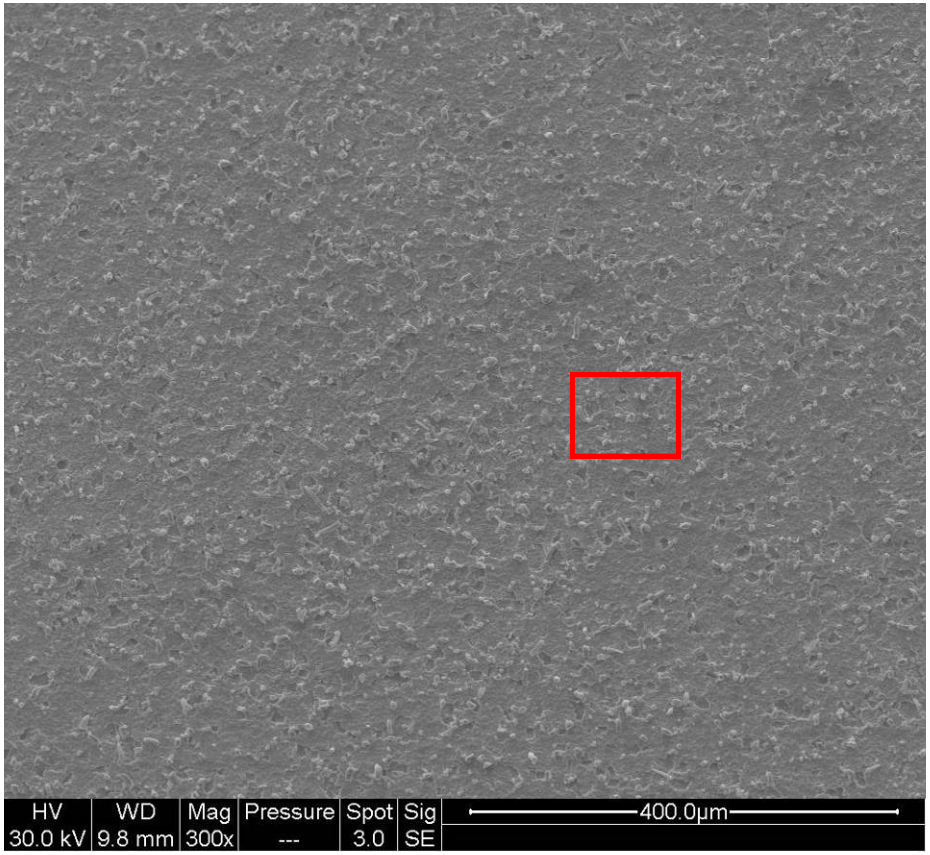


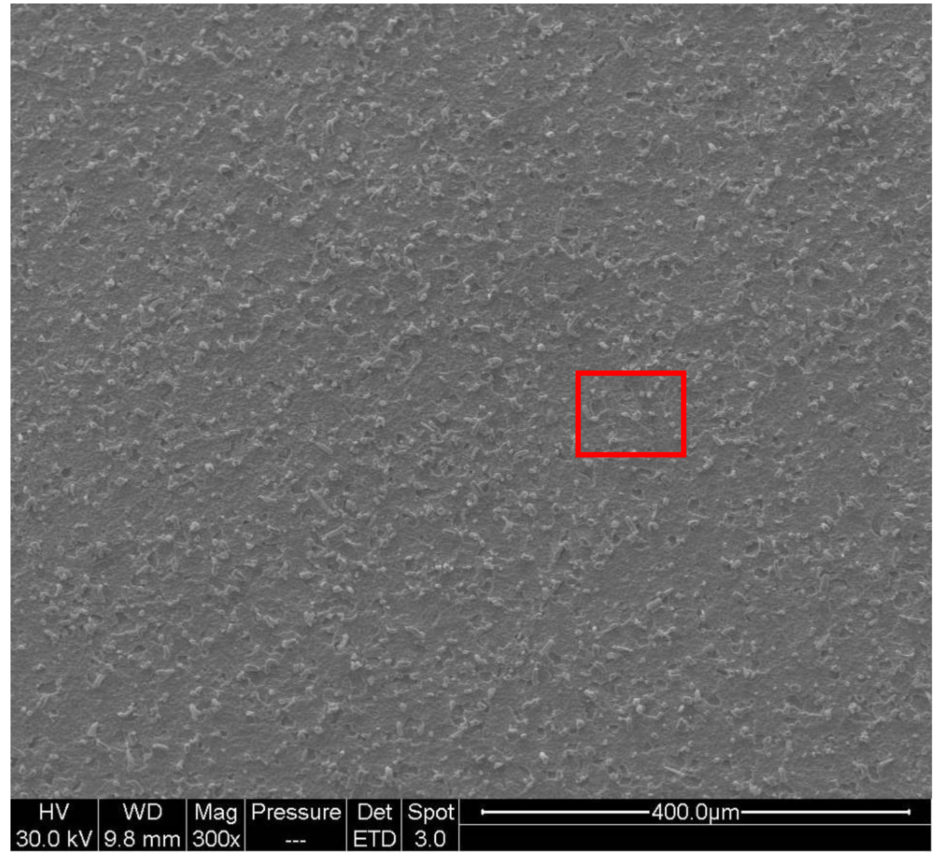
1000 Temperature Cycles



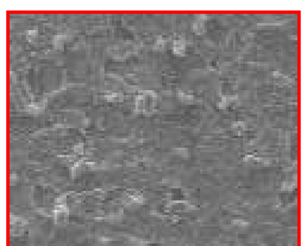
Whisker Growing Arm (1/2)

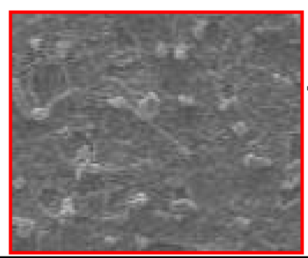
Sn-plated, no underlayer, Cu substrate Sample





1000 Temperature Cycles



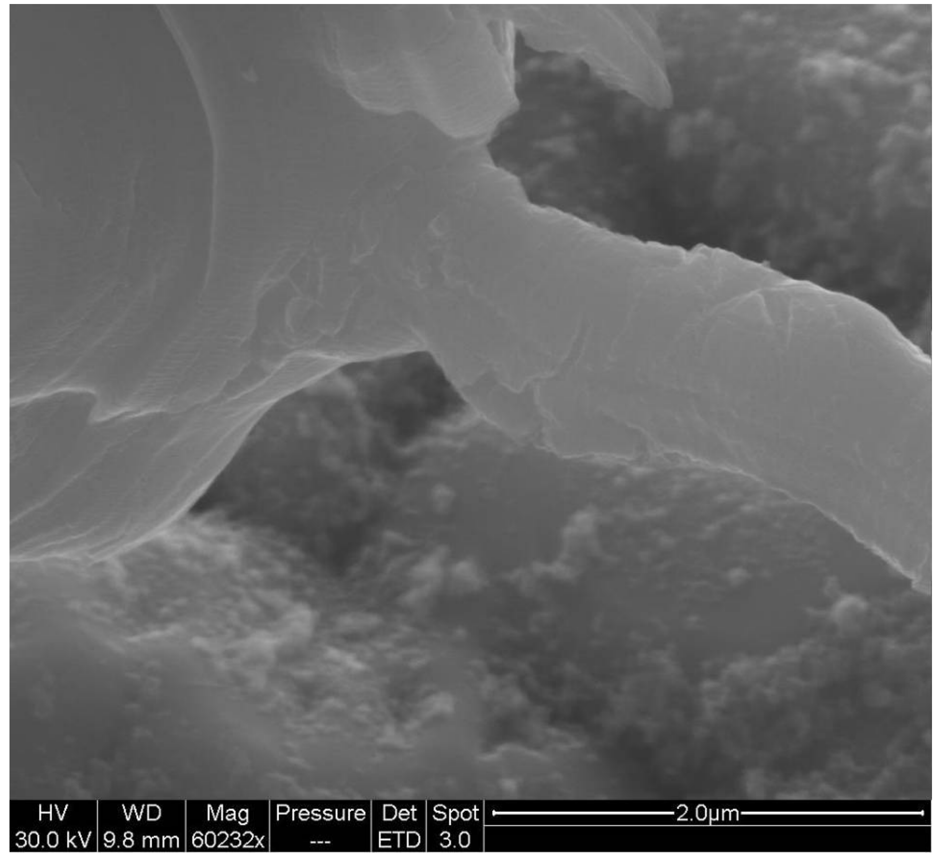


1000 Temperature Cycles
+ 2 months in Temp / Humidity

Whisker Growing Arm (2/2)

Sn-plated, no underlayer, Cu substrate Sample

1000 Temperature Cycles
+ 2 months in Temp / Humidity

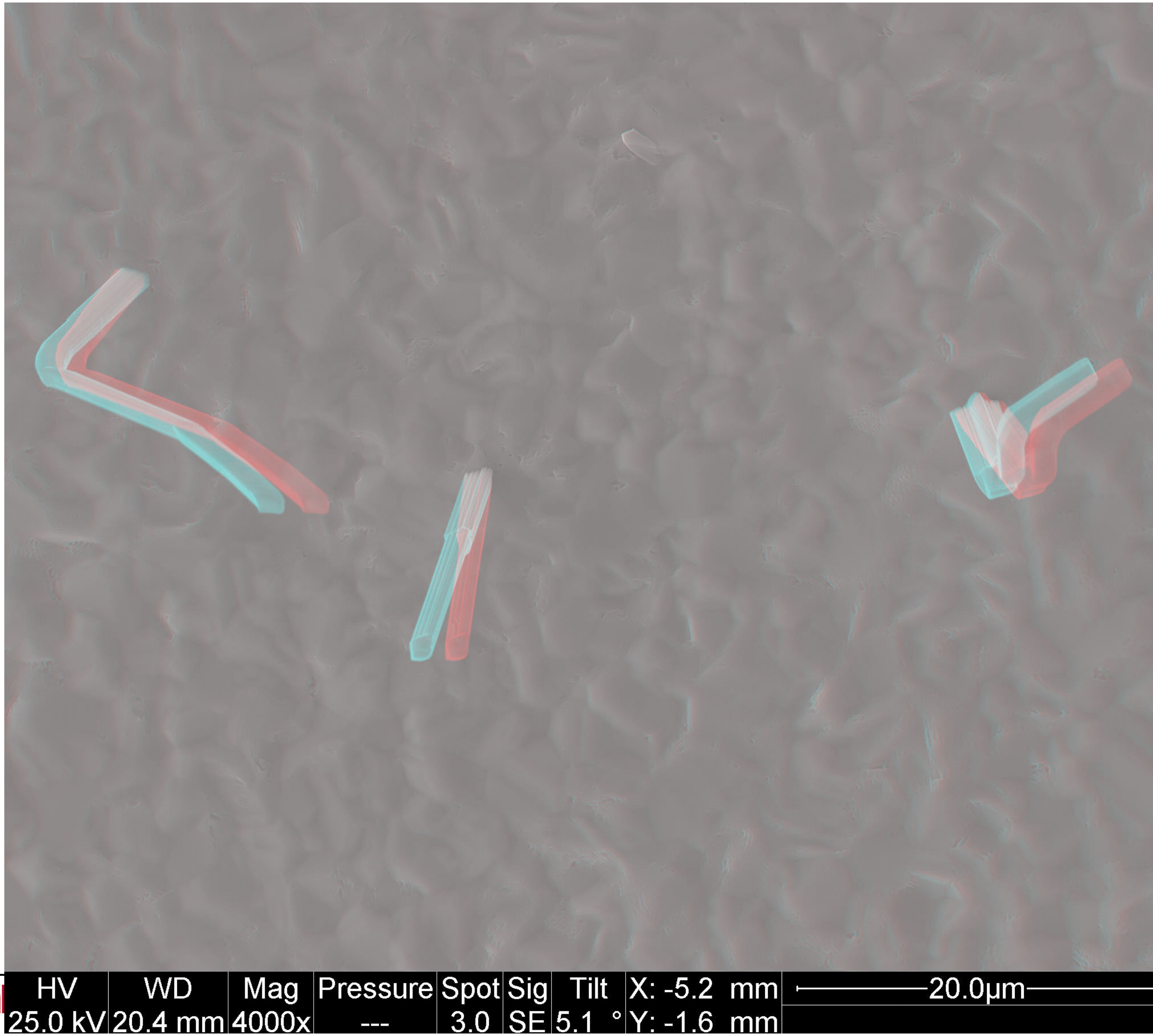


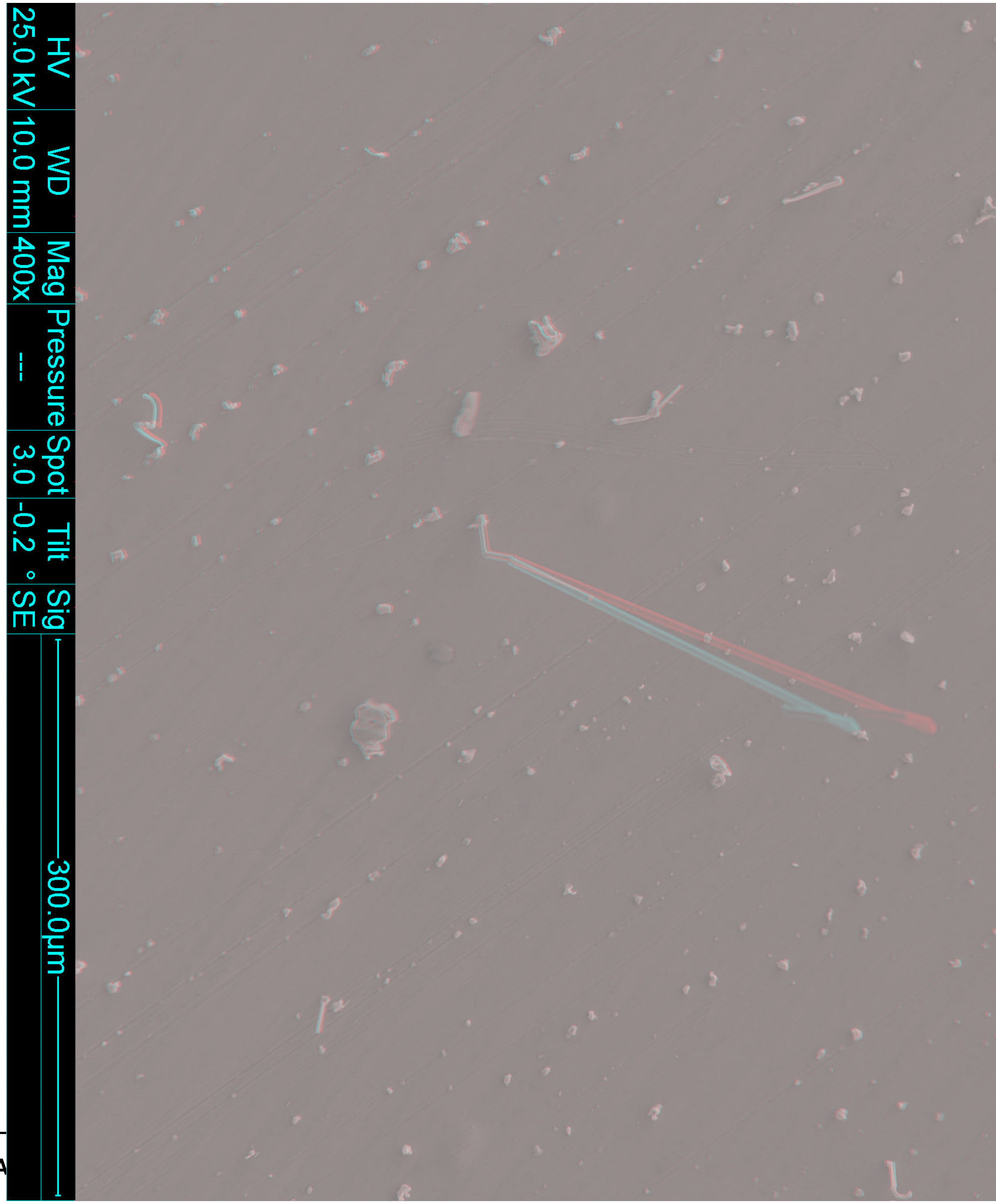
Zoom-in view of the whisker on the left

Whiskers in 3D

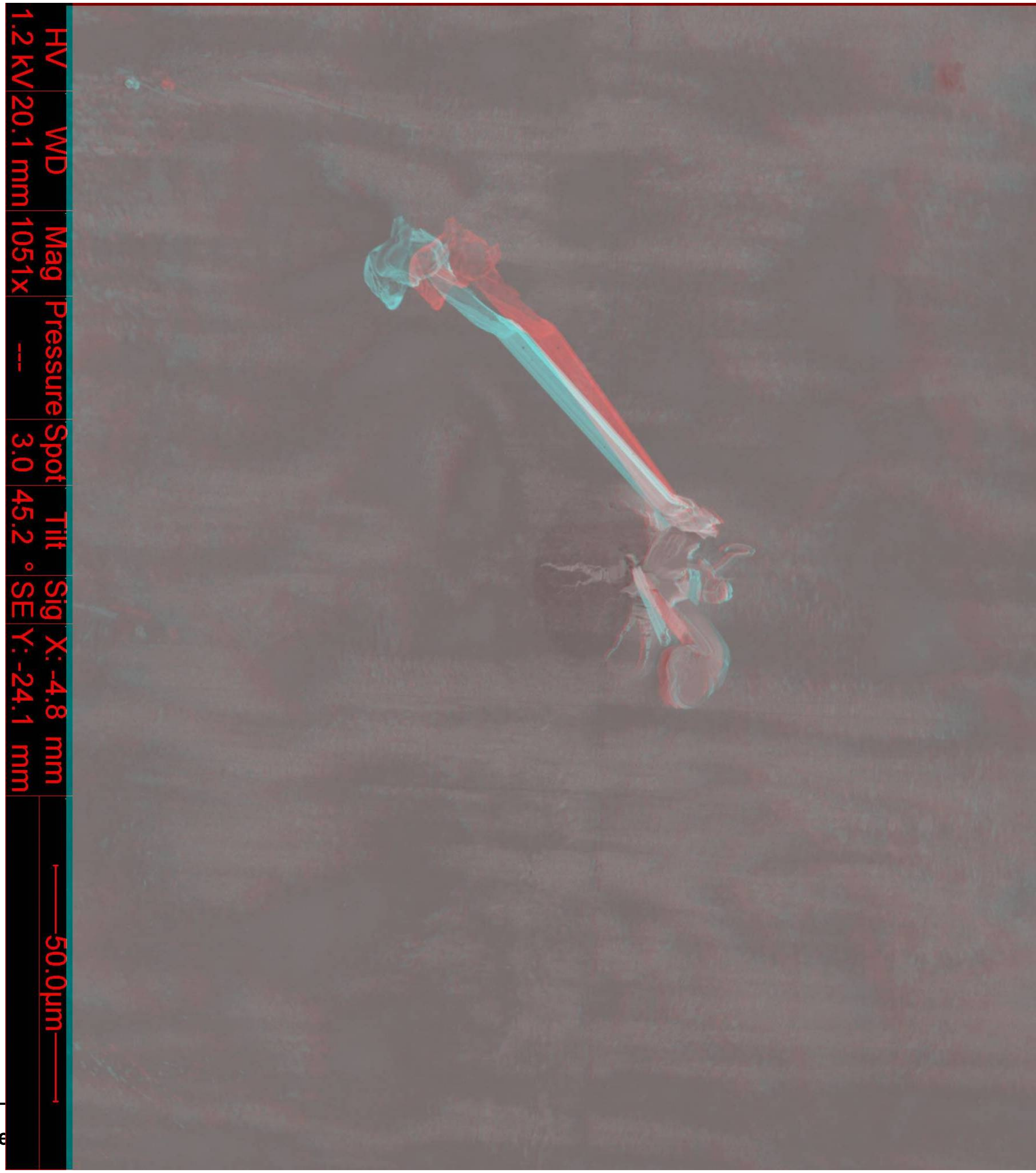
The following images are best viewed using Red-Blue anaglyph glasses

Images clearly demonstrate the 3-Dimensional aspect of whiskers

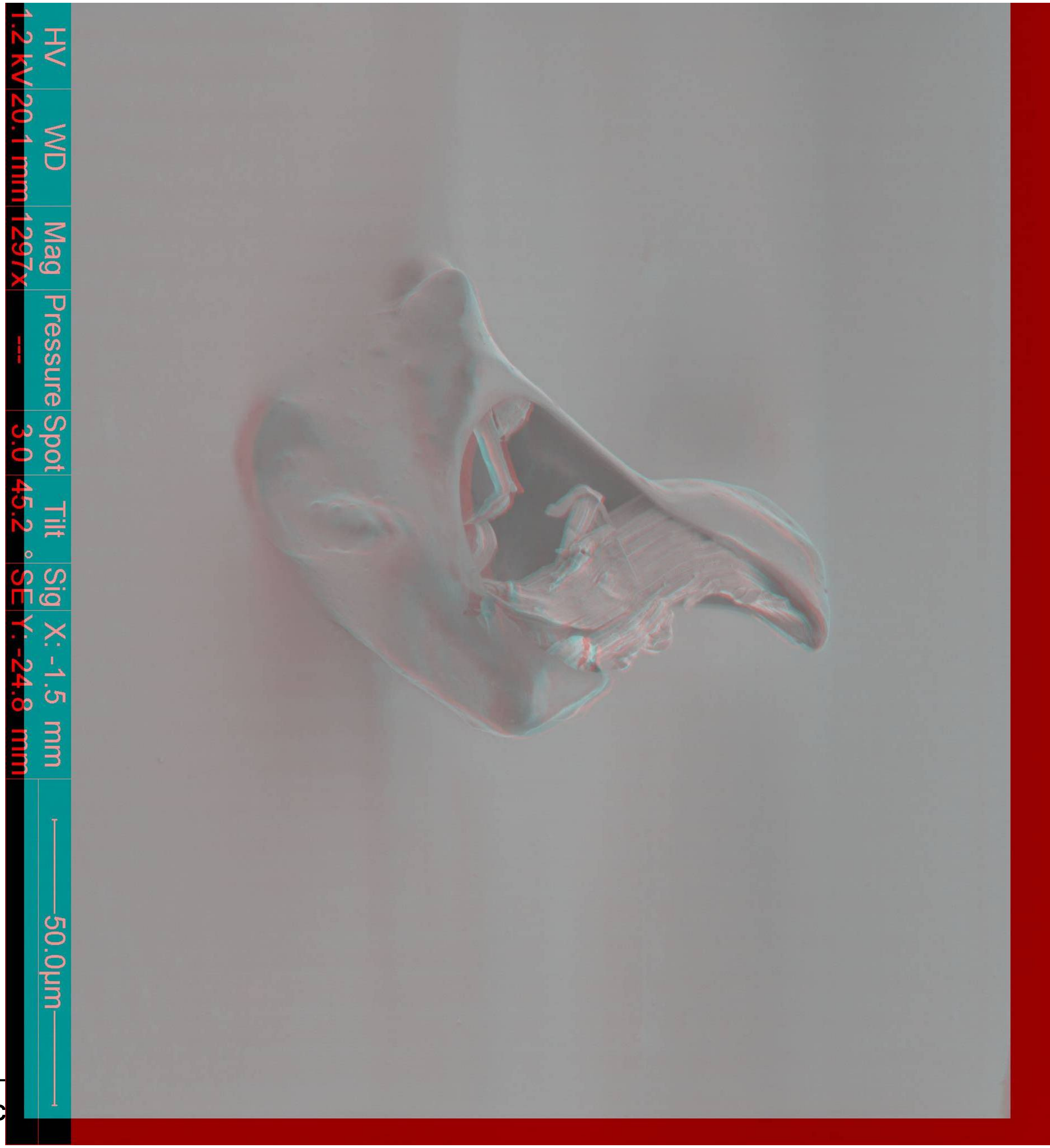

HV 25.0 kV
WD 20.4 mm
Mag 4000x
Pressure ---
Spot 3.0
Sig SE
Tilt 5.1 °
X: -5.2 mm
Y: -1.6 mm
20.0µm


HV
25.0 kV
WD
10.0 mm
Mag
400x
Pressure

Spot
3.0
Tilt
-0.2 °
Sig
SE
300.0µm


HV
1.2 kV
WD
20.1 mm
Mag
1051x
Pressure

Spot
3.0
Tilt
45.2 °
Sig
SE
X: -4.8 mm
Y: -24.1 mm
50.0µm


HV 1.2 kV
WD 20.1 mm
Mag 1297x
Pressure ---
Spot 3.0
Tilt 45.2 °
Sig SE
X: -1.5 mm
Y: -24.8 mm
50.0µm