"Metal Whiskers"
Does Surface Contamination Have an Effect of Whisker Formation?

Terry Munson / Paco Solis
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Kokomo Indiana

Abstract:
Foresite has investigated many whisker failures and found that consistent high levels of chloride, sulfate and amines are present in and around the areas of whisker formation even in hot dry environments with high stress conditions in the solder joints.

Introduction:
Using new techniques to extract pockets of contamination to isolate a specific area we can qualify the ionic residues on the surface and at the subsurface level. We will show supporting evidence that localized levels of contamination have an effect on the dissolution and stress conditions that feed whisker formations.

This paper will review some select failures due to metal whisker formations shorting and data of controlled whisker growth under contamination and now growth under clean conditions of plated and solders surfaces. Devices are not shown in their original failure state to honor client – consultant NDAs.

Case History #1
Zinc Whiskers on raised ESD floor tiles

- ICT hardware on a raised ESD flooring system was found to have intermittent electrical issues with power supplies.
- Transformers and power busses were being shorted by an accumulation of zinc formations carried by cooling fans into system architectures.
- These issues were found to coincide with janitor mopping activity of the ESD floor.

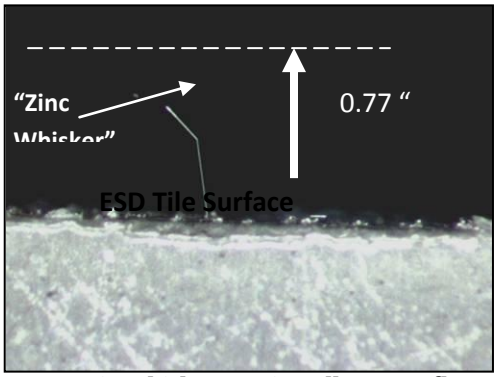

Figure 1 - Tin whisker on zinc alloy ESD floor time

Findings from Initial Case History

- These whiskers are the result of a highly Sulfonated / Amine bearing mop water solution (validated by Ion Chromatography testing). ESD Soap!
- On tiles where these ionic residues have been removed by remedial cleaning and rinsing (with proper chemistries), the whisker formations are greatly retarded or completely eliminated.
- Contaminated tiles in our lab continue to produce whiskers to this day.

Case history #2 SAC 304 Alloy

- SOT Device in high density SMT PCA
- SAC304 Alloy
- Dry Warm Conditions
- Formation in 2-3 weeks

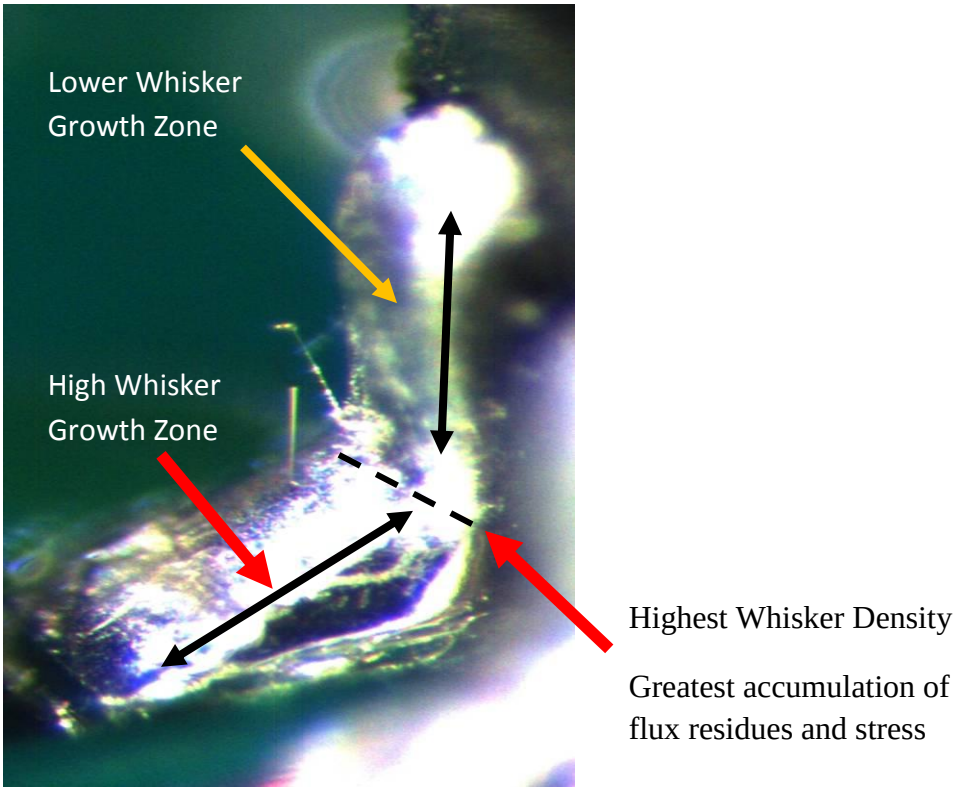

Figure 2- Whiskers on SOT gull lead with SAC 304 alloy termination

During reflow, high concentrations of flux residues flow up the termination and accumulate at the gull wing bend. Although solder reflow occurs from toe to shoulder, the flux accumulation settles at the lead bend. A second item noted was the discovery of nano-whiskers which form from the flux line extending over 200 µm in serpentine length and under 1µm in width.

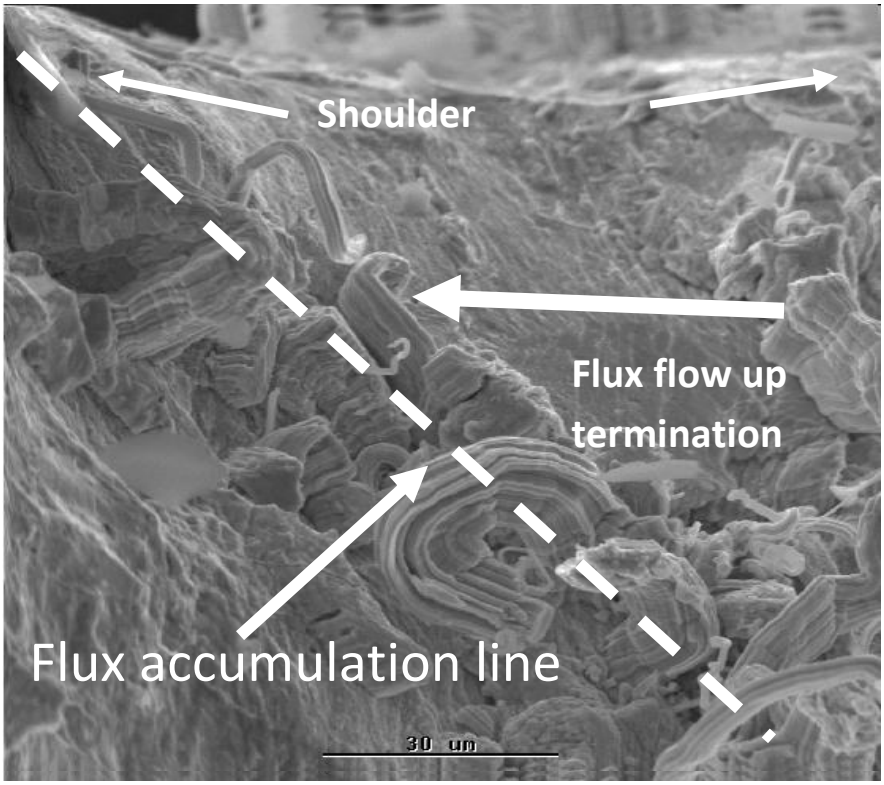

Figure 3 - SEM Image of SOT gull wing termination

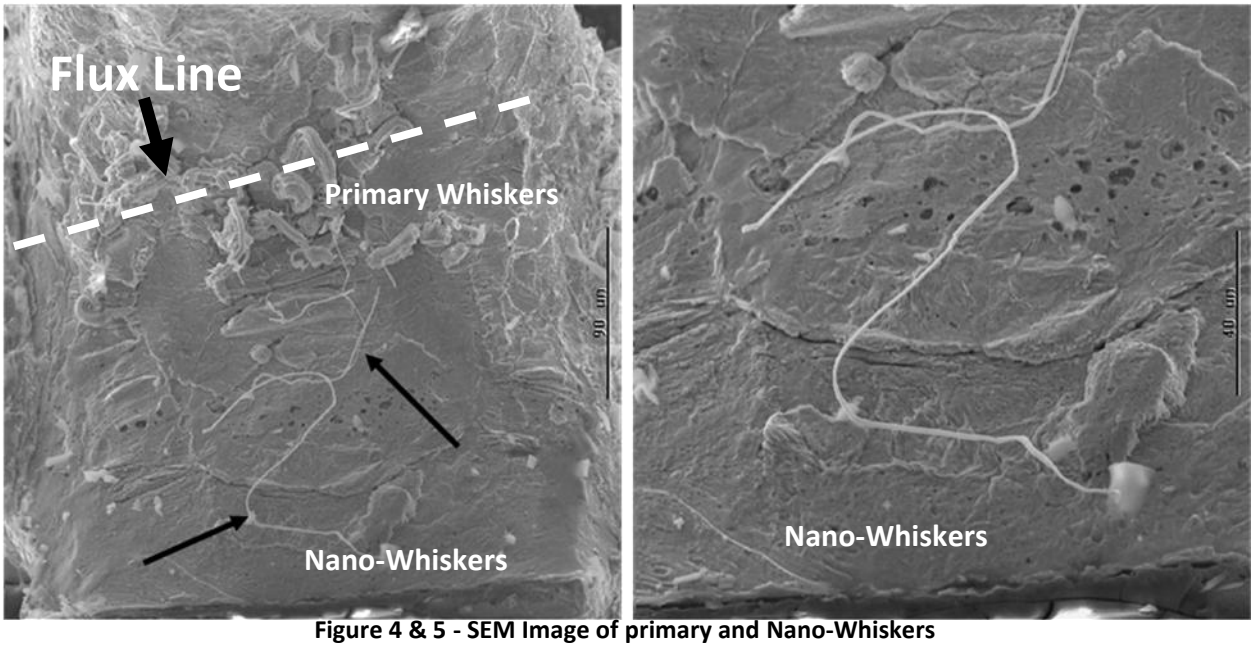

Figure 4 & 5 - SEM Image of primary and Nano-Whiskers

These nano-whiskers continuously extrude from the surface as well as from the larger primary whiskers. They settle on the surface and are freely fractured and fall away with little force.

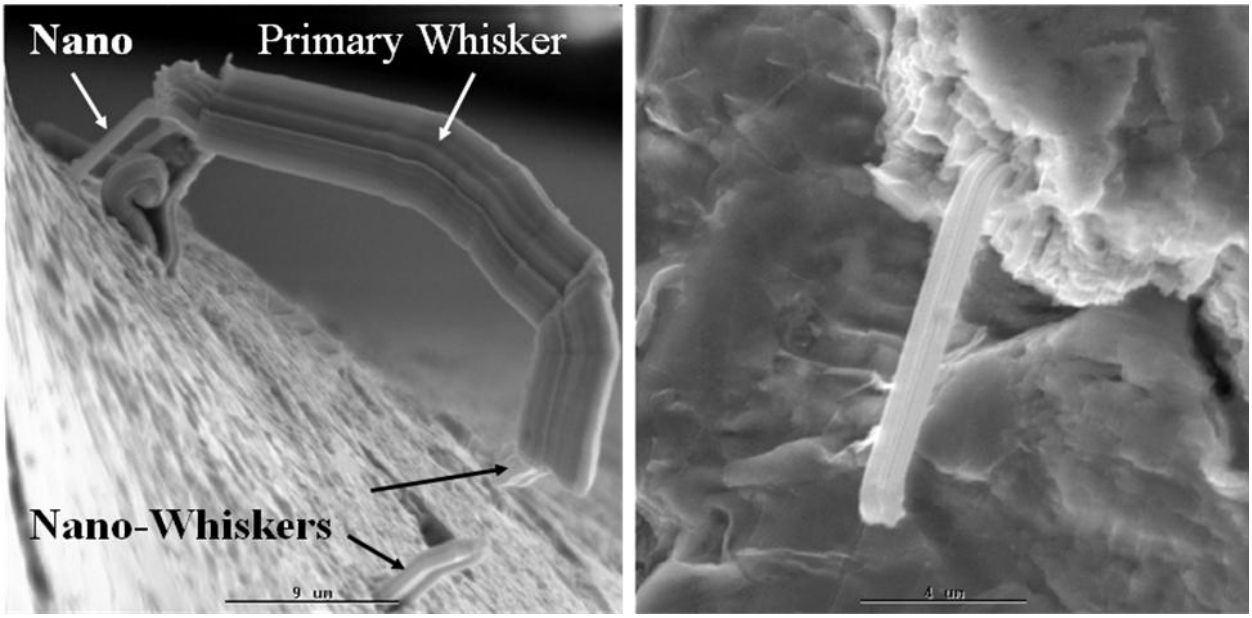

Figure 6 & 7 - SEM Image of primary and Nano-Whiskers

In the below cross-section image these whiskers were recorded showing surface and subsurface attributes to their formation.

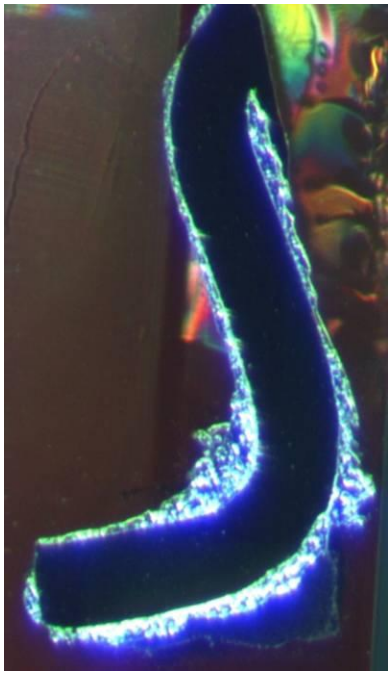

Figure 8 – Optical Image of primary whisker in cross-section

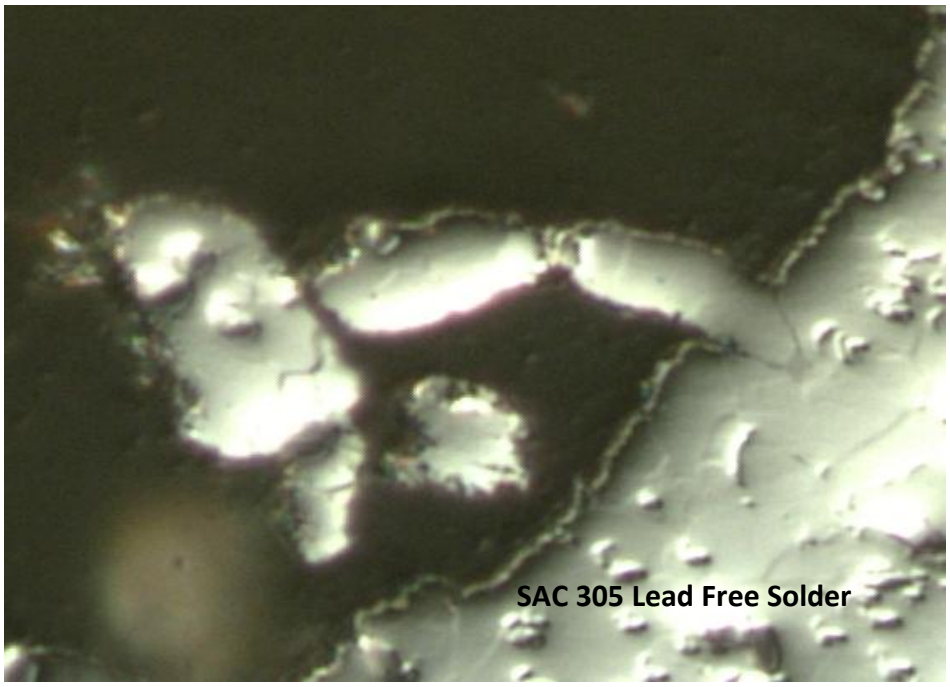

Figure 9 – Optical Image primary whisker in cross-section at 1000X

In cross-section a single grain dislocation can be seen at the whisker extrusion site. More samples like these are needed to further study this condition. This sample was prepared with pH 9 gamma colloidal silica slurry for grain delineation. The sample was unfortunately compromised before it was submitted to SEM analysis.

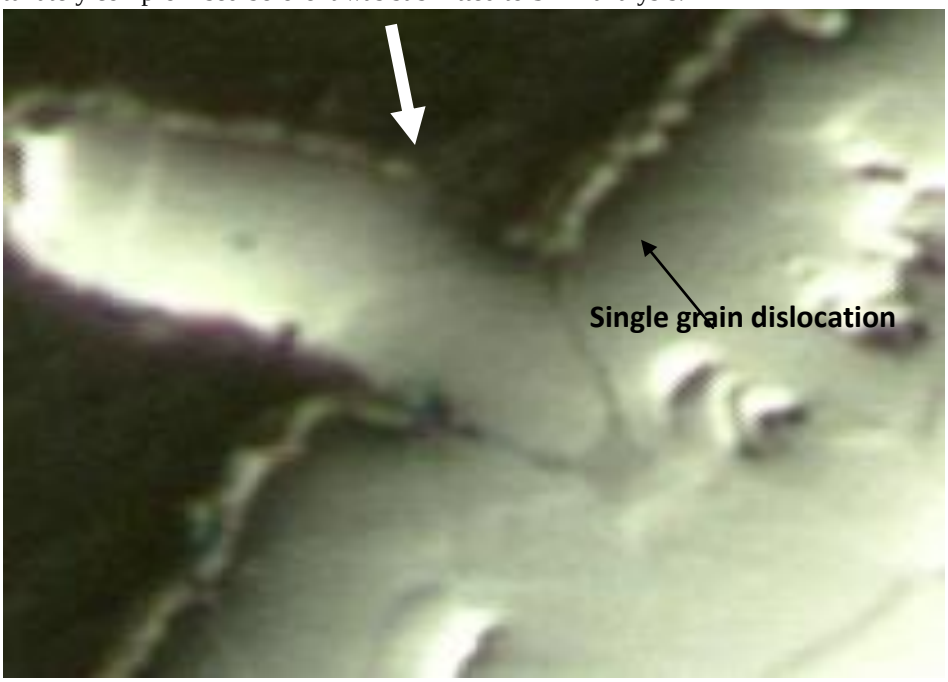

Figure 10 – Optical Image of primary whisker in cross-section at 1000X (digitally magnified)

Chemical analysis data:
Analysis samples for ion chromatography were collected with the C3 cleanliness test system.

Figure 11 –Cleanliness test system

The ion chromatography data below shows high Chloride, sulfate, and Ammonia contaminations coinciding with the highest occurrences and density of whisker growth (shown in red).

Table 1

all values are in ug/in2		Ion Chromatography			
Sample Area	**Location**	**Chloride**	**Sulfate**	**Ammonia**	**WOA**
Assembly SN 4YQ5006T					
Q10 area	Via	3.91	2.04	0	0
	Pads	4.11	1.47	2.34	21.02
	Component	2.14	0.24	1.21	11.74
Q8 area	Via	4.15	1.68	0	0
	Pads	3.98	0.74	0	12.36
	Component	1.41	0.11	0	8.69
R7 area	pads	2.11	1.69	0	17.95
	component	1.79	0.47	0	4.75
U1 area (14pin DIP)	Via	3.14	2.11	0	0
	Pads	2.47	0.67	0	22.61
	Component	2.04	0	0	9.17
Refence 8 pin DIP	Via	3.77	1.21	0	0
	Pads	2.11	0.69	0.47	15.42
	Component	1.36	0	0.26	10.41
Reference Board	Board	1.79	1.02	1.01	10.63
no via area					

Table 2

all values are in ug/in2		Ion Chromatography			
Sample Area	**Location**	**Chloride**	**Sulfate**	**Ammonia**	**WOA**
Assembly SN 4YQ5006S					
Q10 area	Via	4.85	3.11	0	0
	Pads	3.98	2.74	2.32	24.36
	Component	1.24	0	3.11	19.54
Q8 area	Via	1.22	1.44	0	0
	Pads	0.95	0.36	0	16.24
	Component	0.77	0	0	11.47
R7 area	pads	1.69	1.04	0	15.24
	component	1.55	0	0	6.96
U1 area (14pin DIP)	Via	1.05	0.77	0	0
	Pads	0.78	0.59	0.85	20.04
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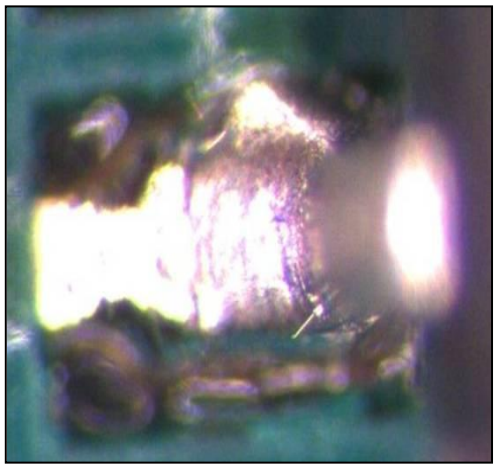

Figure 12

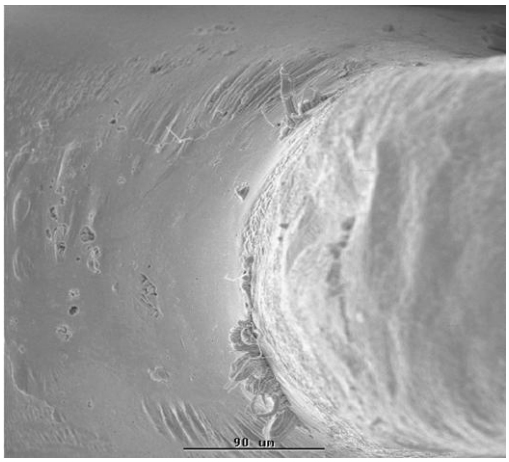

Figure 13

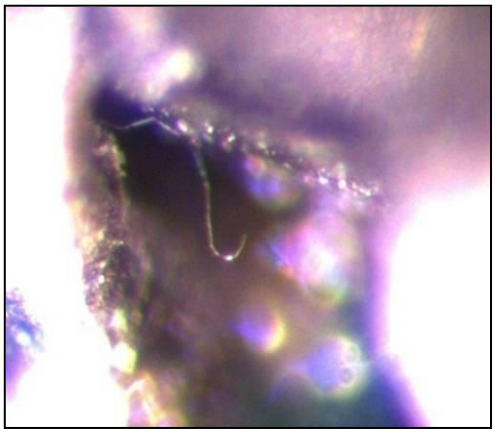

Figure 14

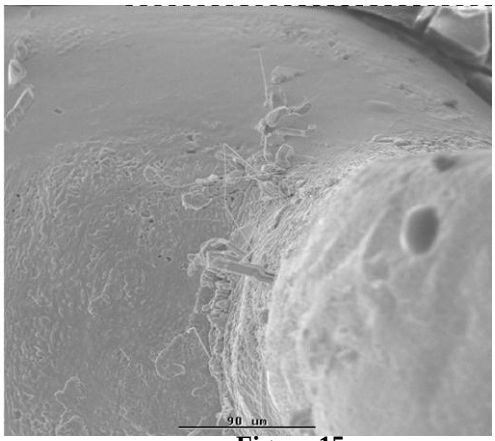

Figure 15

Preliminary findings from Case History #2

- Localized D.I. steam cleaning with a saponifier has proven effective at preventing reoccurrences when total ionic contamination has been reduced.

- Inversely - areas doped with high levels of ionic contamination show a significantly higher occurrence of whisker formations.

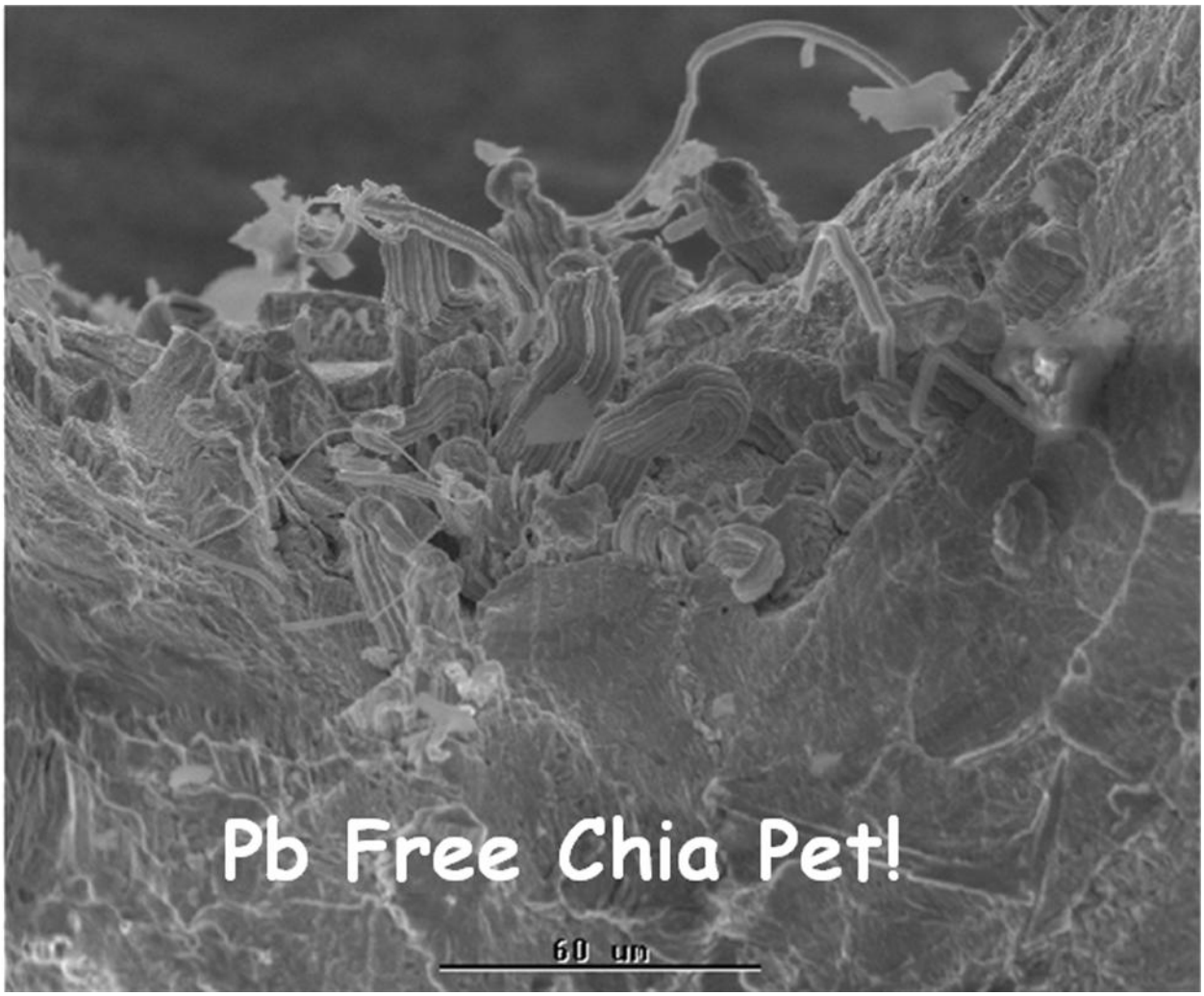

Figure 16 – Results of accelerated whisker growth from select doping of terminations

Current analysis Case history #3 Tin whiskers in D-sub jack screw

Whiskers are forming in the jack screws of lead free connectors. Preliminary data has shown high levels of Chlorides, Sulfates, and Amines are present in the Jack Screws. Analysis is ongoing to study the contamination effects in these locations and the retardation effects of cleaning. Data on this analysis is will published in updates to this paper.

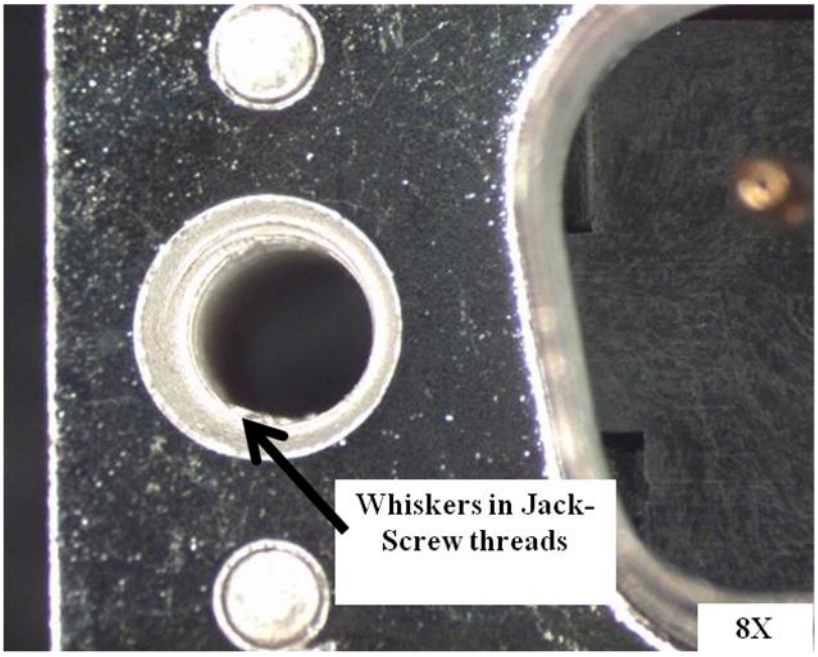

Figure 17 – optical images of whiskers on jack screw threads

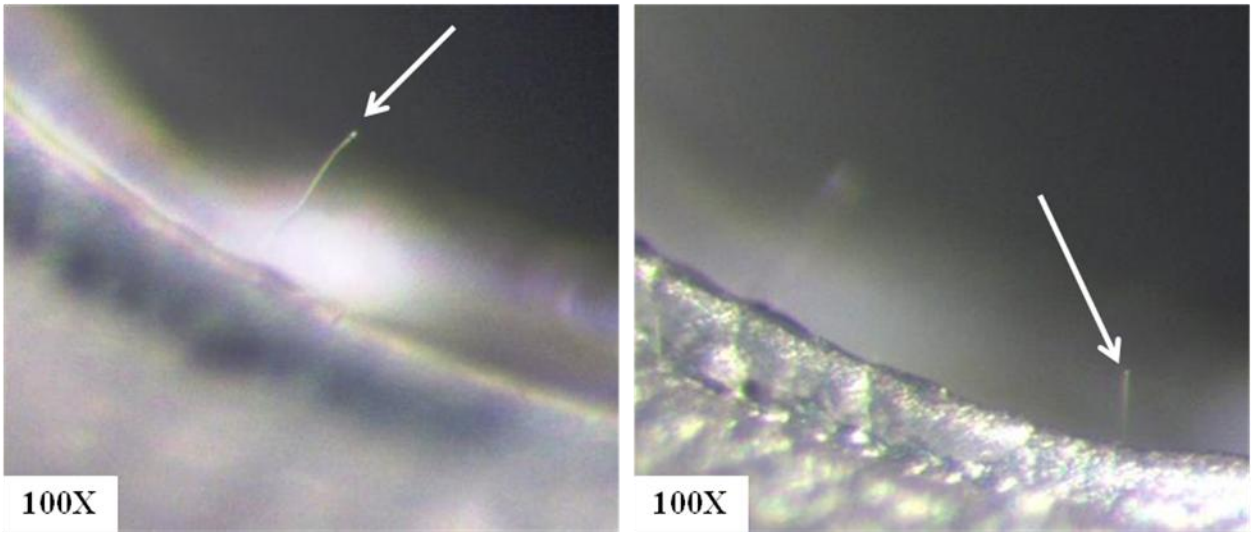

Figure 18 & 19 – optical images of whiskers on jack screw threads

Where do we go now?

- Continue to collect data points
- DOE in progress to recreate the failure mode at-will with a vehicle to better understand the activation energy, contamination thresholds, and stresses for the whisker formation.
- Preliminary findings have lead to a grant awarded to continue research.
- Return next year with an update!

“Metal Whiskers - Does Surface Contamination have an impact on Whisker Formation?”

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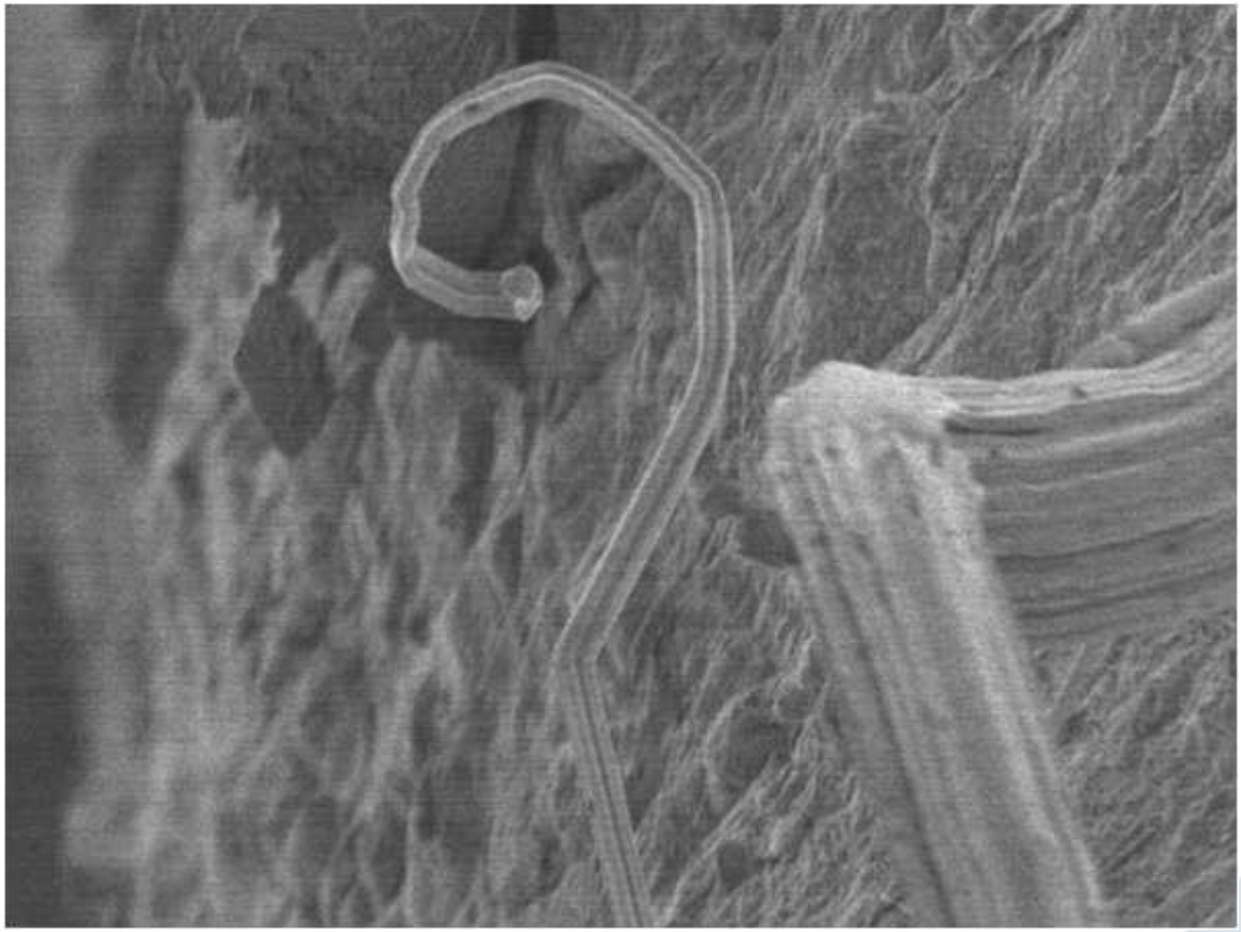


Intent

- Discuss some select whisker findings not previously addressed (relevant to Pb Free processing).
- Share some examples and data from a few of our findings
  - Without violating client NDAs
- Future Plans
- Question and answers

A question not addressed…

Are we missing something?

- During the past years the occurrence of whisker formations have been responsible for an untold number of field failures on lead free assemblies…..
- Why…? We are just not looking close enough!
- Based on our incoming inspection of customer Failures, we have instituted whisker inspection as a normal function of our incoming flow for data gathering.

Background

- Using new techniques of extracting pockets of contamination to isolate specific area, we can qualify the ionic residues on the surface and at the subsurface level.

- We will show supporting evidence that localized levels of contamination have an effect on the dissolution conditions that feed the stress point of the whisker formation.

Background Cont'd

- Foresite has investigated numerous whisker failures and found consistent high levels of **chloride**, **sulfate** and **amines** present in and around the areas of whisker formation. This included whiskers that have formed in hot dry environments.

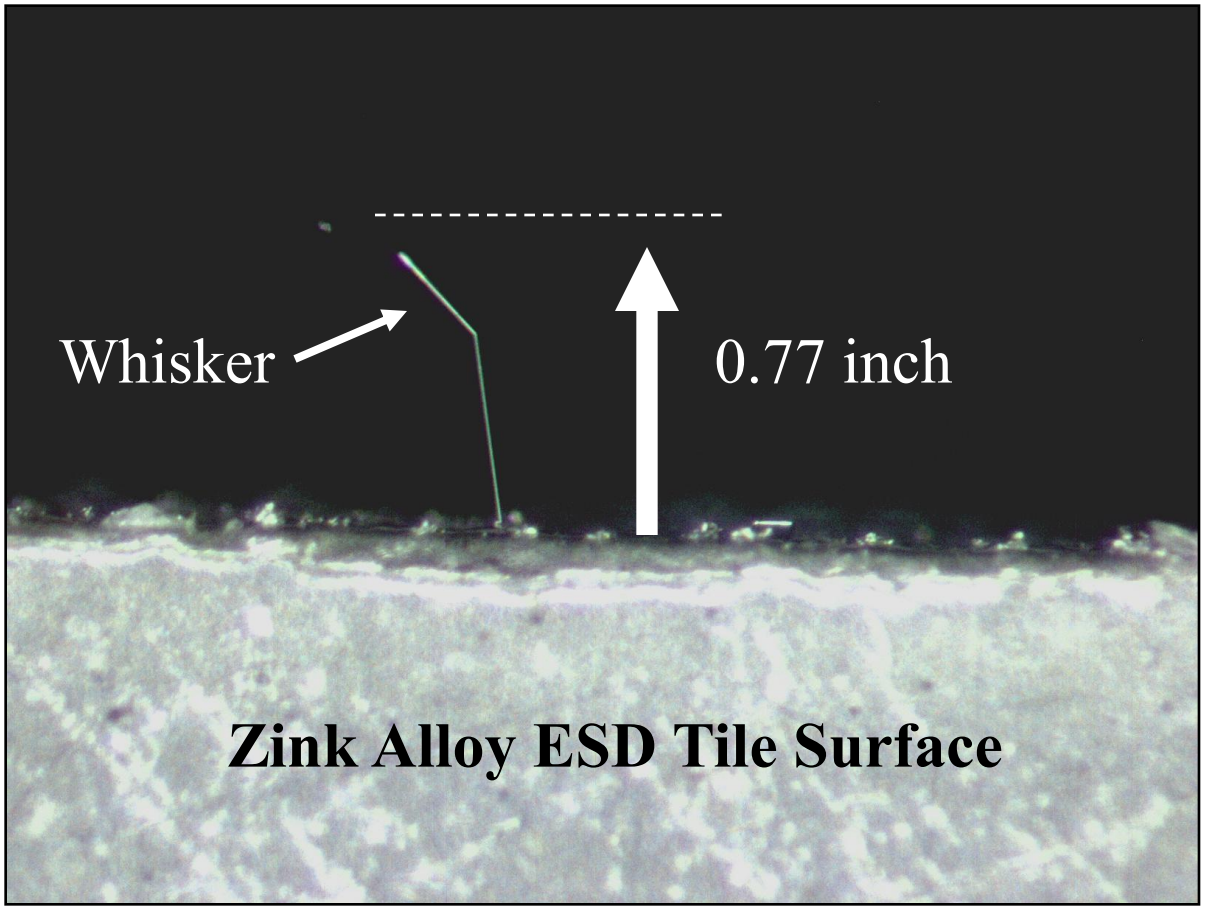
- This paper will review some select failures due to metal whisker formation shorting and data of controlled whisker growth under contaminated and no growth under clean conditions of plated and soldered surfaces.

Case History #1

- ICT hardware on a raised ESD flooring system was found to have intermittent electrical issues with power supplies.
- Transformers and power busses were being shorted by an accumulation of zinc formations carried by cooling fans into system architectures.
- These issues were found to coincide with janitor mopping activity of the ESD floor.

Images of failure mode on assemblies not shown due to client NDAs

Findings
Zinc Whiskers from raised ESD Floor Tiles



Images of failure mode on assemblies not shown due to client NDAs

Findings from Initial study

- These whiskers are the result of a highly Sulfonated / Amine bearing mop water solution (validated by Ion Chromatography testing). ESD Soap!
- On tiles where these ionic residues have been removed by remedial cleaning and rinsing (with proper chemistries), the whisker formations are greatly retarded or completely eliminated.
- Contaminated tiles in our lab continue to produce whiskers to this day.

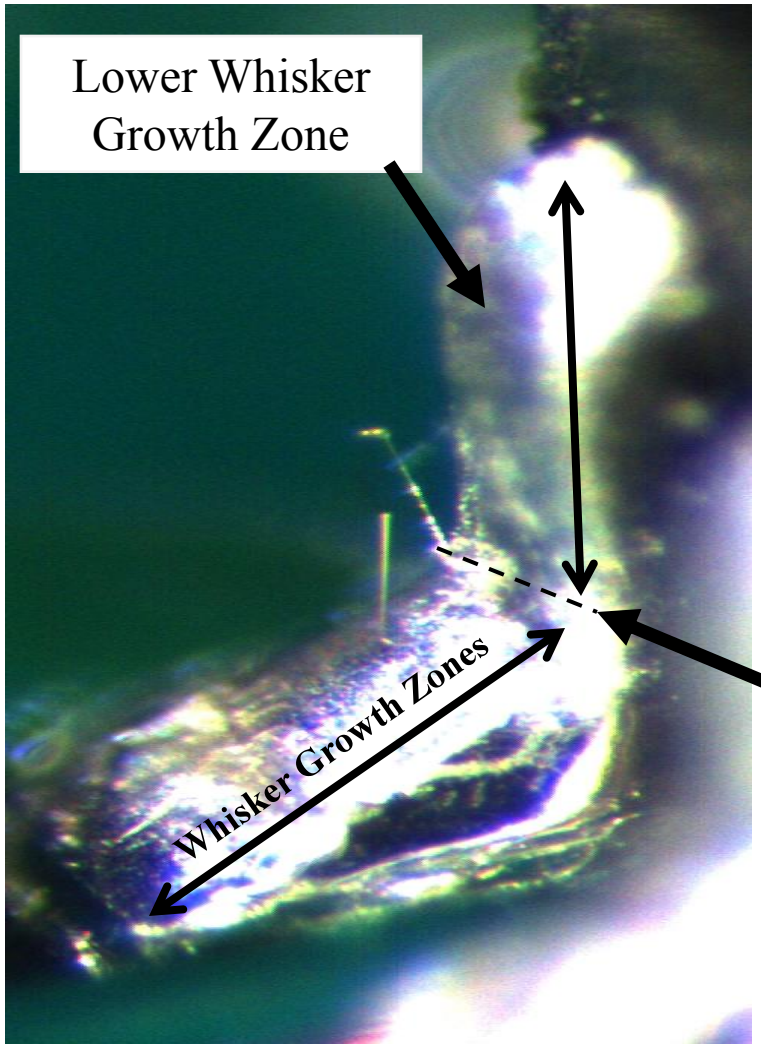
Case History #2 SAC304

- SOT Device
- SAC304 Alloy
- Dry Warm Conditions
- Formation in 2-3 weeks

Images of failure mode on assemblies not shown due to client NDAs

Some Anatomy

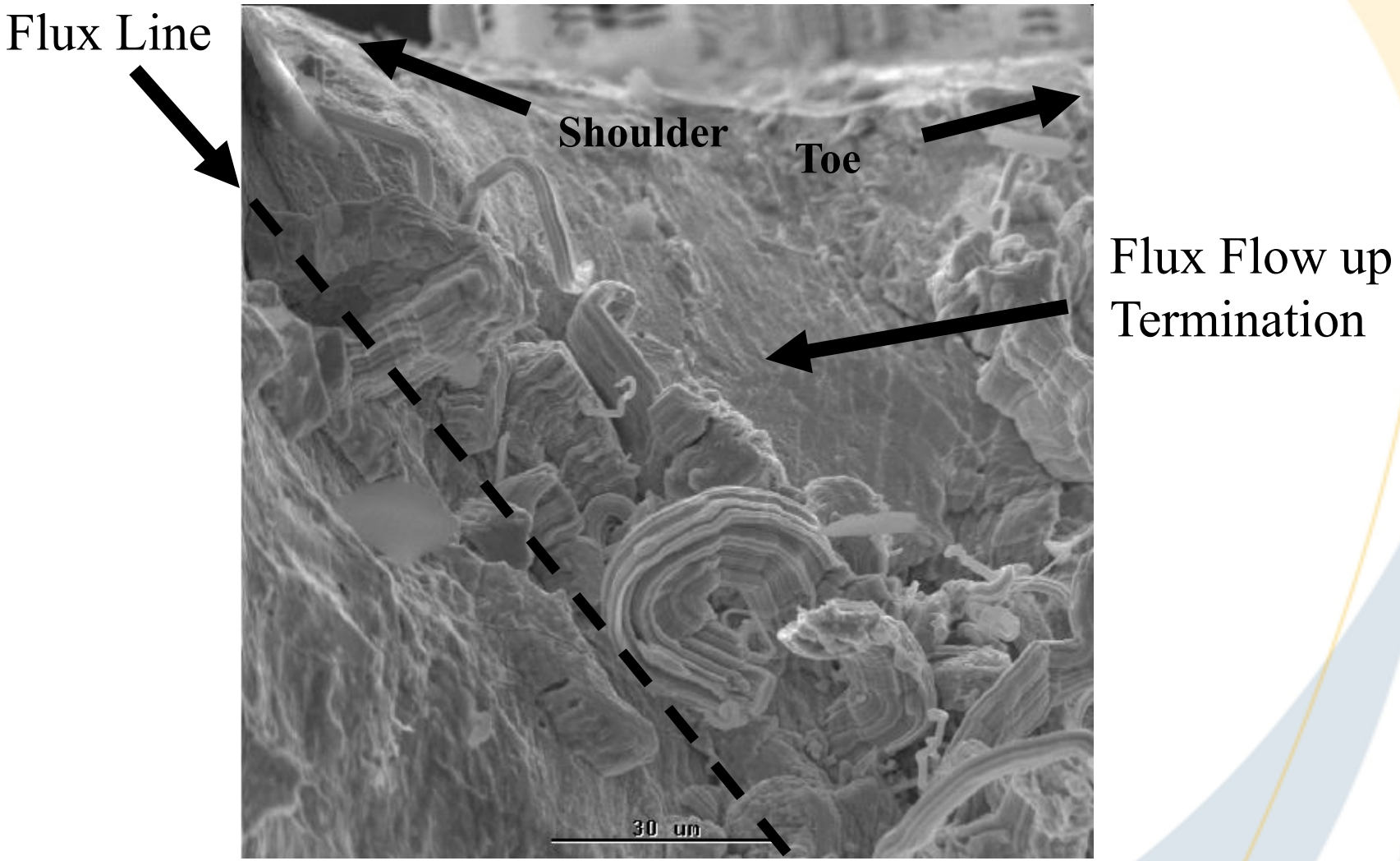
Gull Wing Lead



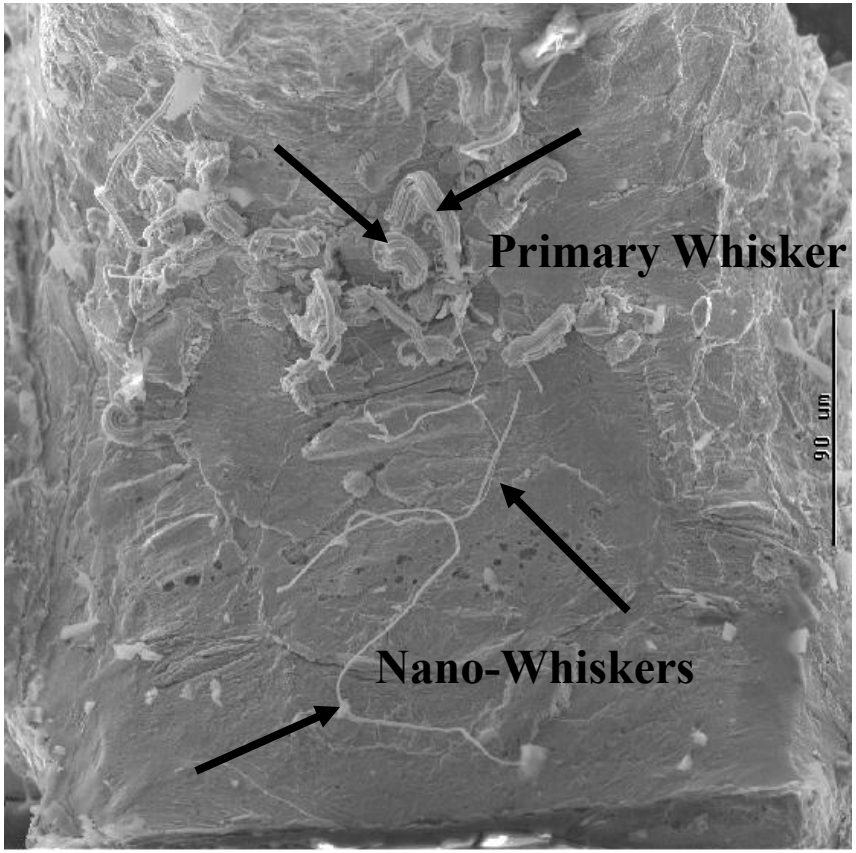
Highest Whisker Density.

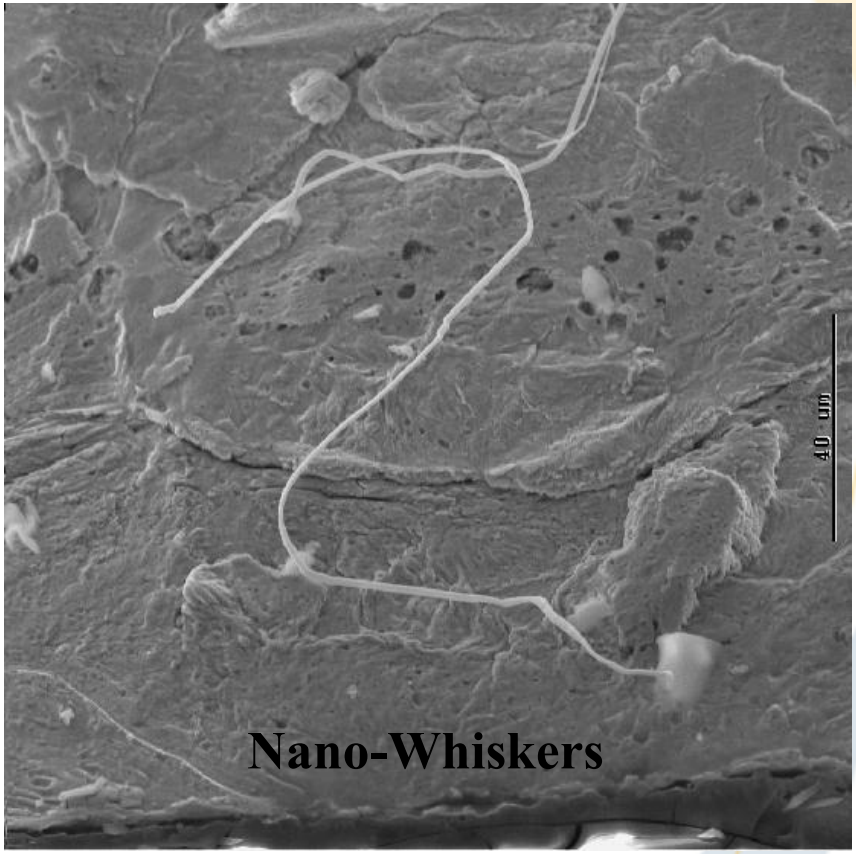
Greatest accumulation of flux residues and stress

SEM Image – Top end of reflow zone



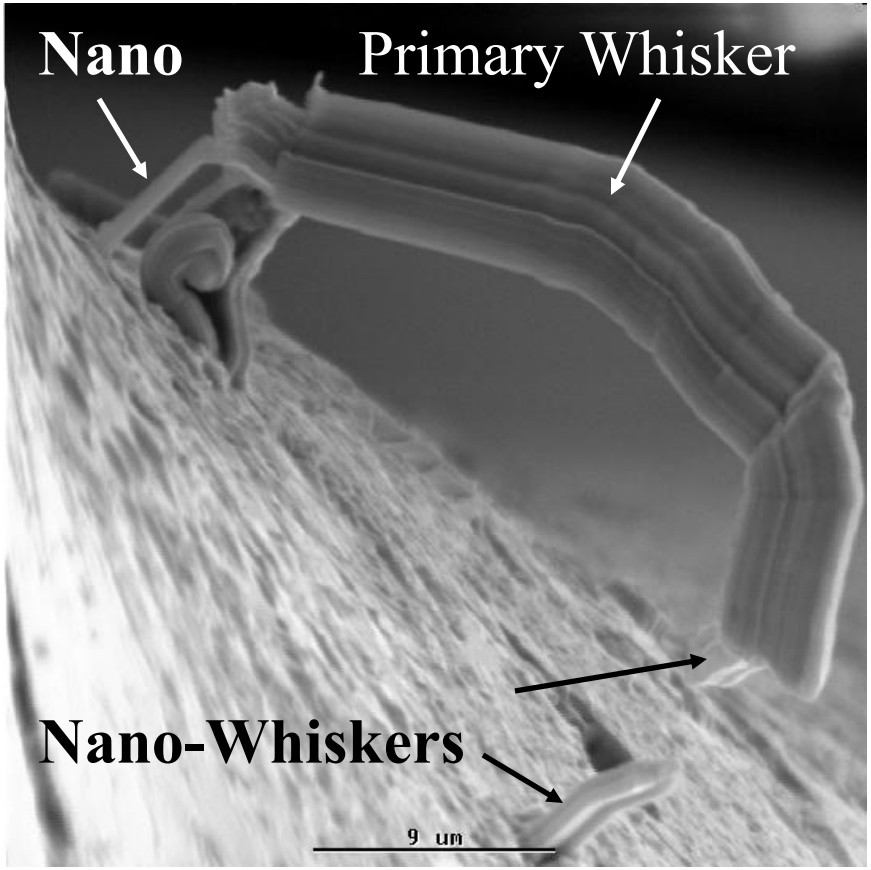
Nano Whiskers!

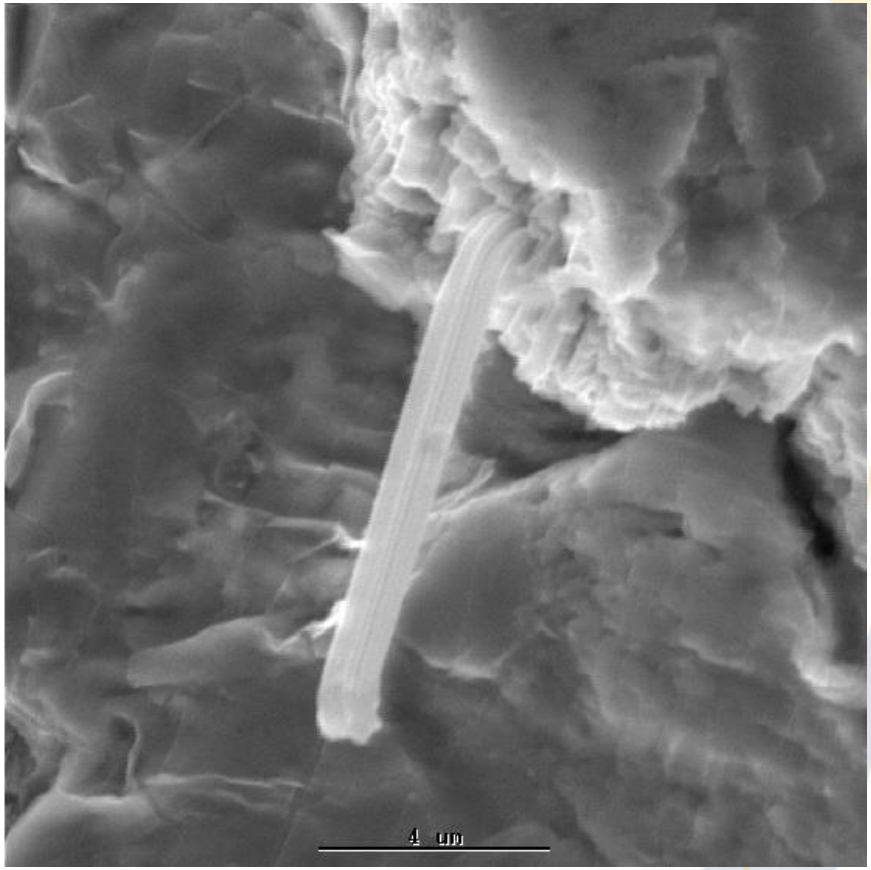




Serpentine length > 200µm

More Nano-Whiskers



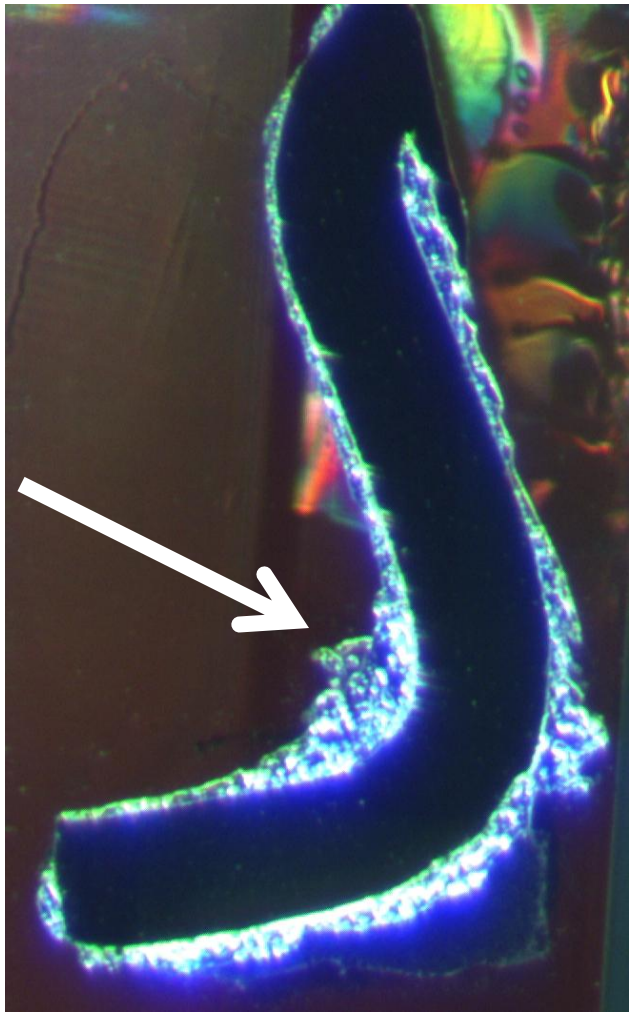


Nano-Whiskers have been measured <1µm in width

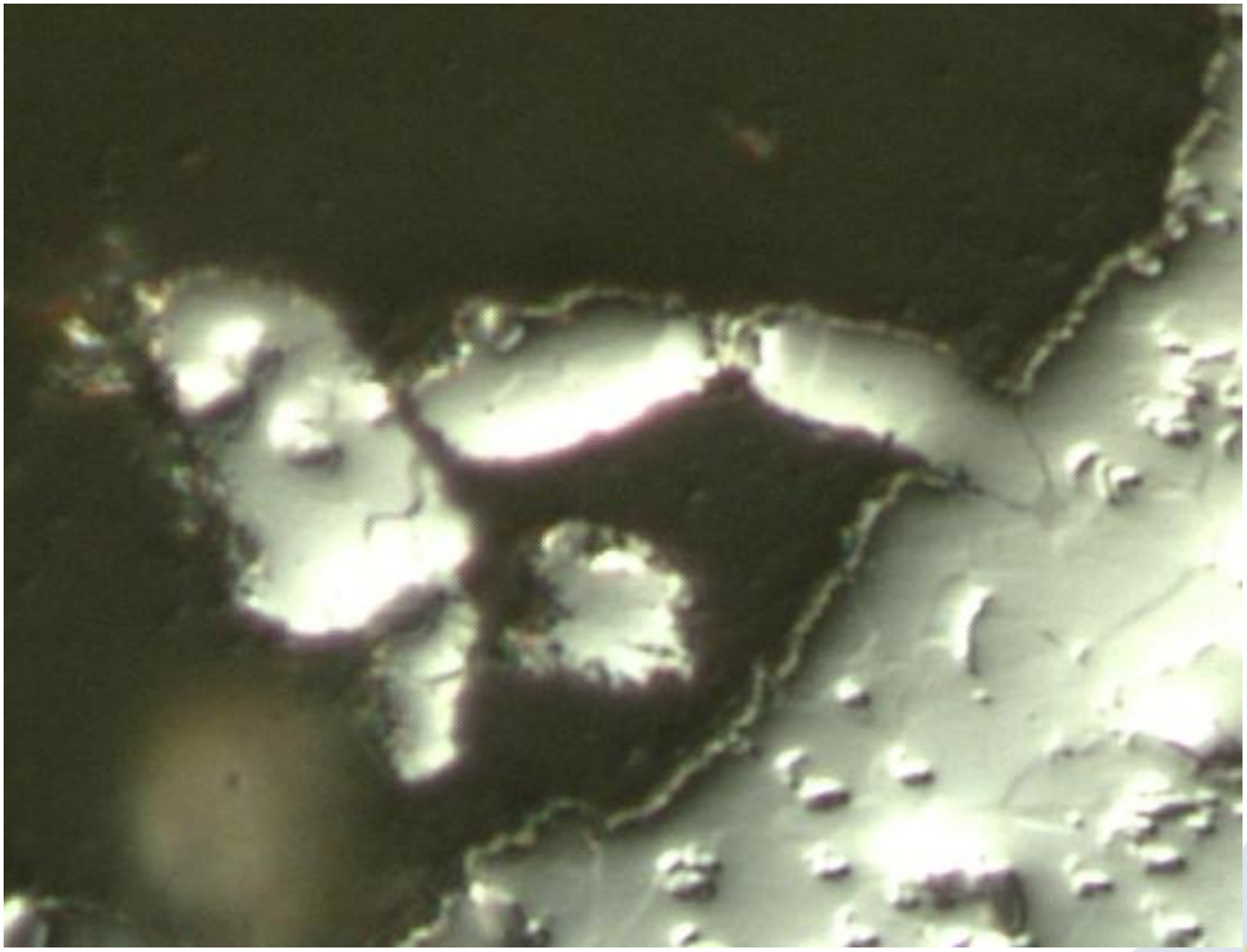
Termination in Cross-section

Highest Whisker Density.

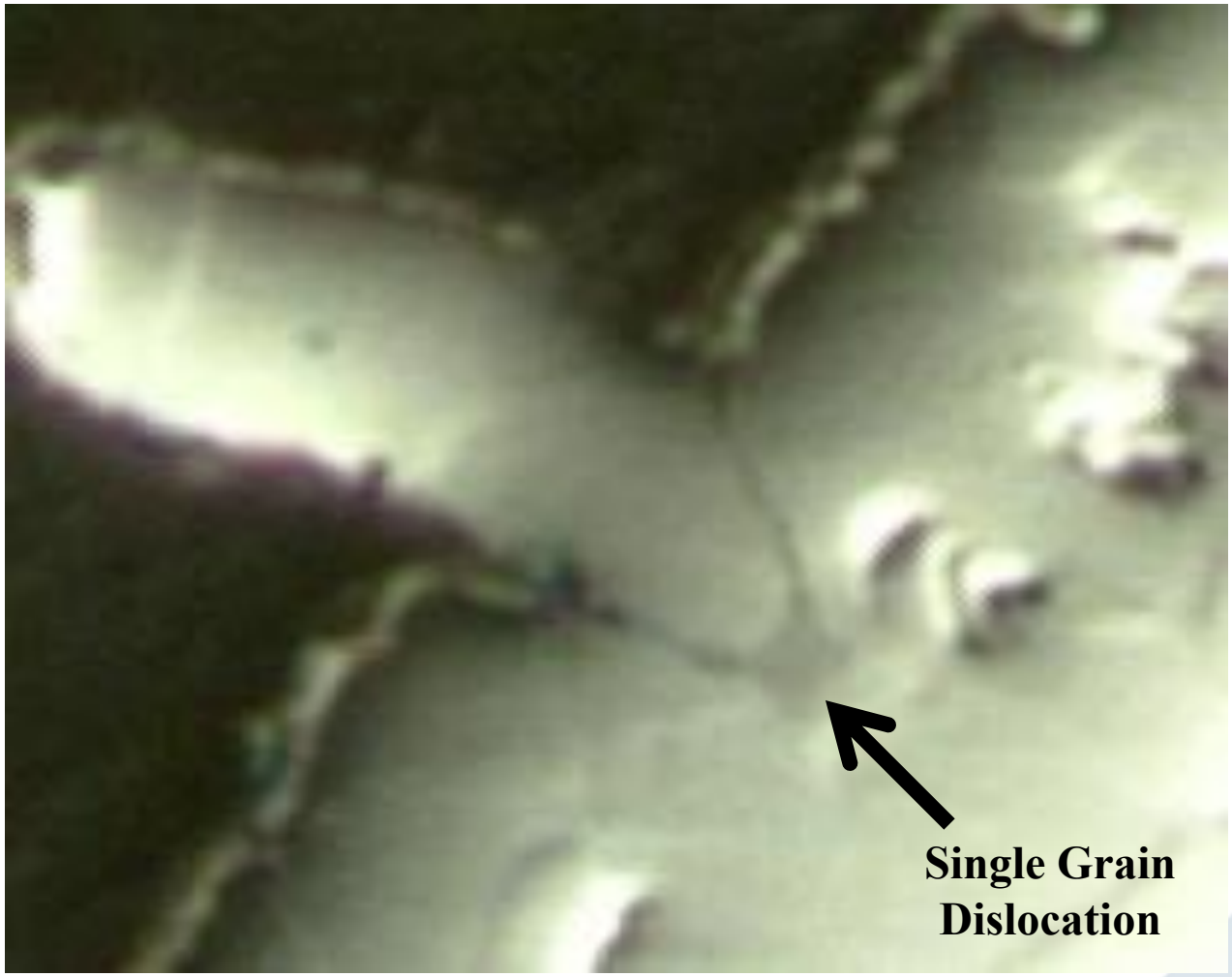
Greatest accumulation of flux residues, stress, and solder slump



Cross-section at 1000X

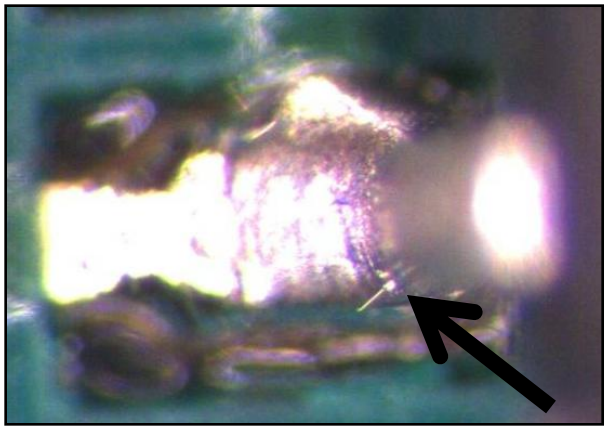


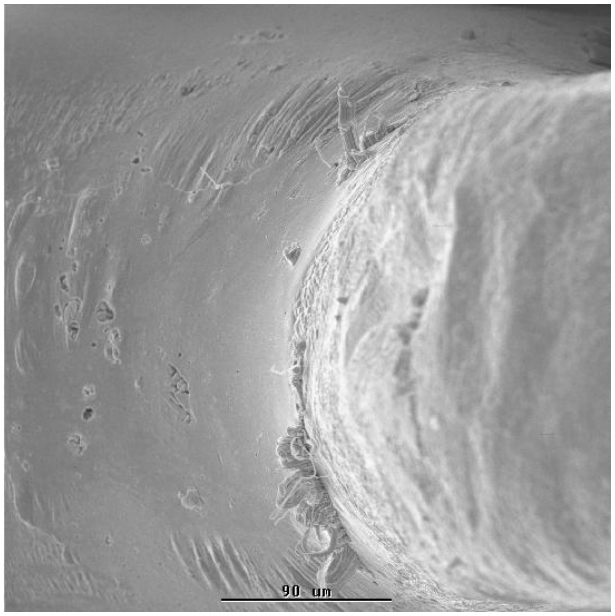
Cross-section at 1000X



Samples were collected with the C3 Cleanliness Test System developed by Foresite

Case History #2 Data





all values are in ug/in2		Ion Chromatography			
Sample Area	**Location**	**Chloride**	**Sulfate**	**Ammonia**	**WOA**
Assembly "X"					
Area #1 SOT	Via	3.91	2.04	0	0
	Pads	**4.11**	**1.47**	**2.34**	21.02
	Component	**2.14**	**0.24**	**1.21**	11.74
Area #2 SOT	Via	4.15	1.68	0	0
	Pads	3.98	0.74	0	12.36
	Component	1.41	0.11	0	8.69
Area #3 SMT Resistor	pads	2.11	1.69	0	17.95
	component	1.79	0.47	0	4.75
Area #4 14 pin Dip	Via	3.14	2.11	0	0
	Pads	2.47	0.67	0	22.61
	Component	2.04	0	0	9.17
Refence area 8 pin DIP	Via	3.77	1.21	0	0
	Pads	2.11	0.69	0.47	15.42
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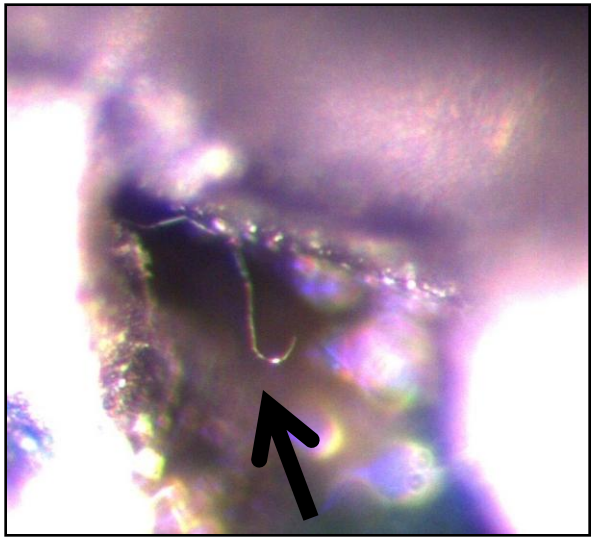
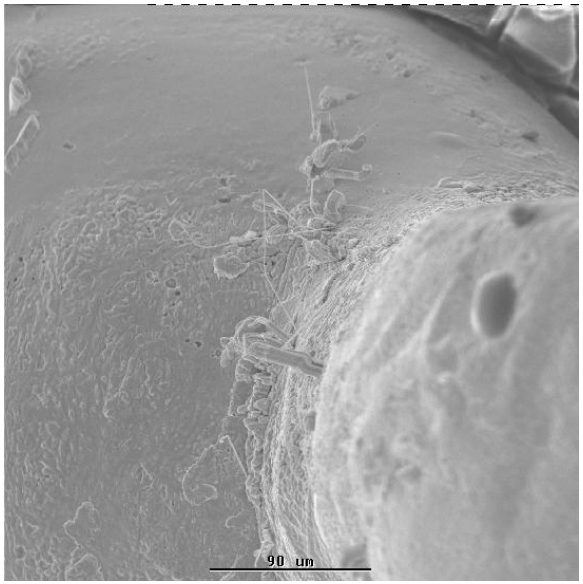
Case History #2 Data Con't





all values are in ug/in2		Ion Chromatography			
Sample Area	**Location**	**Chloride**	**Sulfate**	**Ammonia**	**WOA**
Assembly "Y"					
Area #1 SOT	Via	4.85	3.11	0	0
	Pads	**3.98**	**2.74**	**2.32**	24.36
	Component	**1.24**	**0**	**3.11**	19.54
Area #2 SOT	Via	1.22	1.44	0	0
	Pads	0.95	0.36	0	16.24
	Component	0.77	0	0	11.47
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	component	1.55	0	0	6.96
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	Pads	0.78	0.59	0.85	20.04
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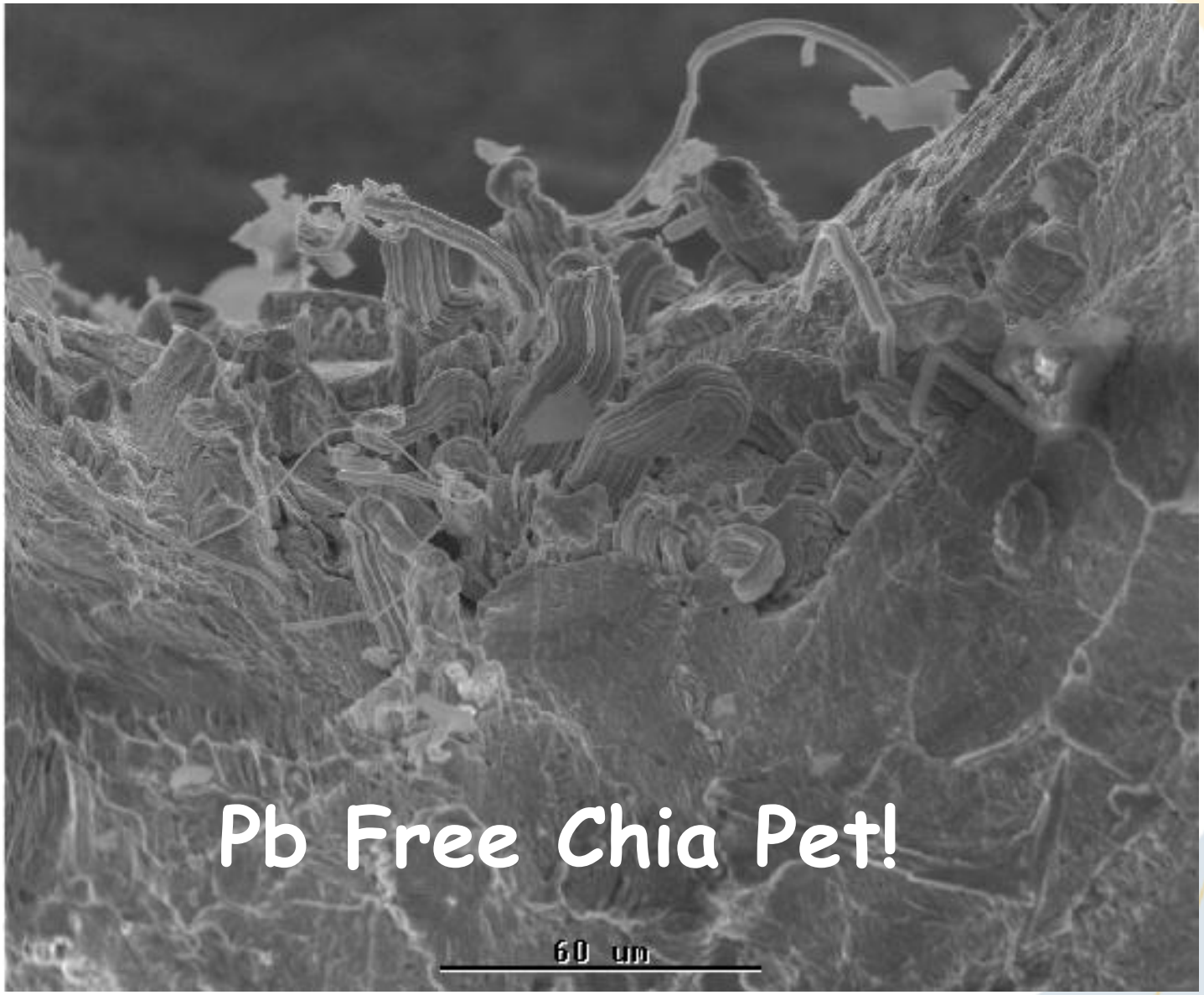
Preliminary Findings Case #2

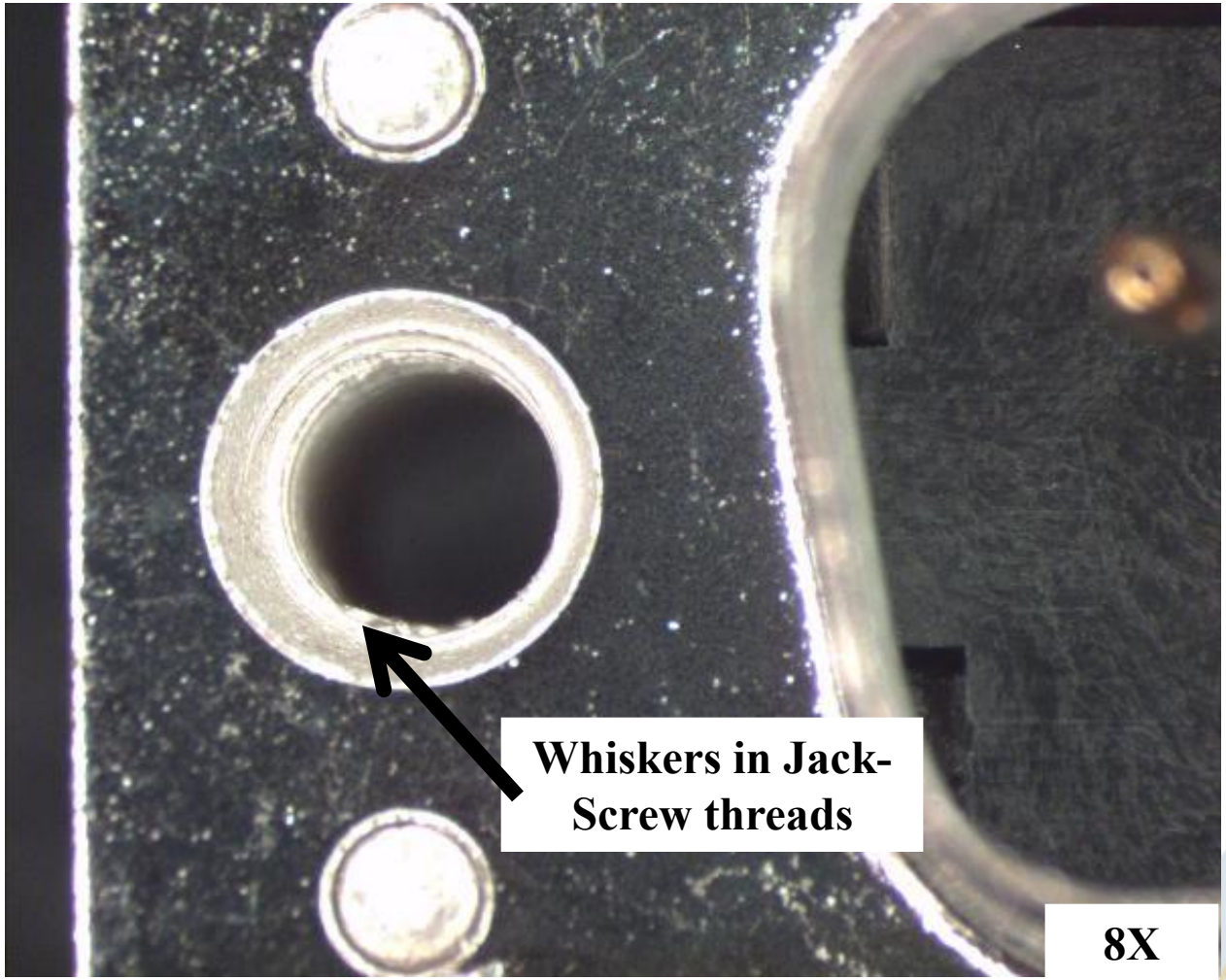
- Localized D.I. steam cleaning with a saponifier has proven effective at preventing reoccurrences when total ionic contamination has been reduced.

- Inversely - areas doped with high levels of ionic contamination show a significantly higher occurrence of whisker formations.

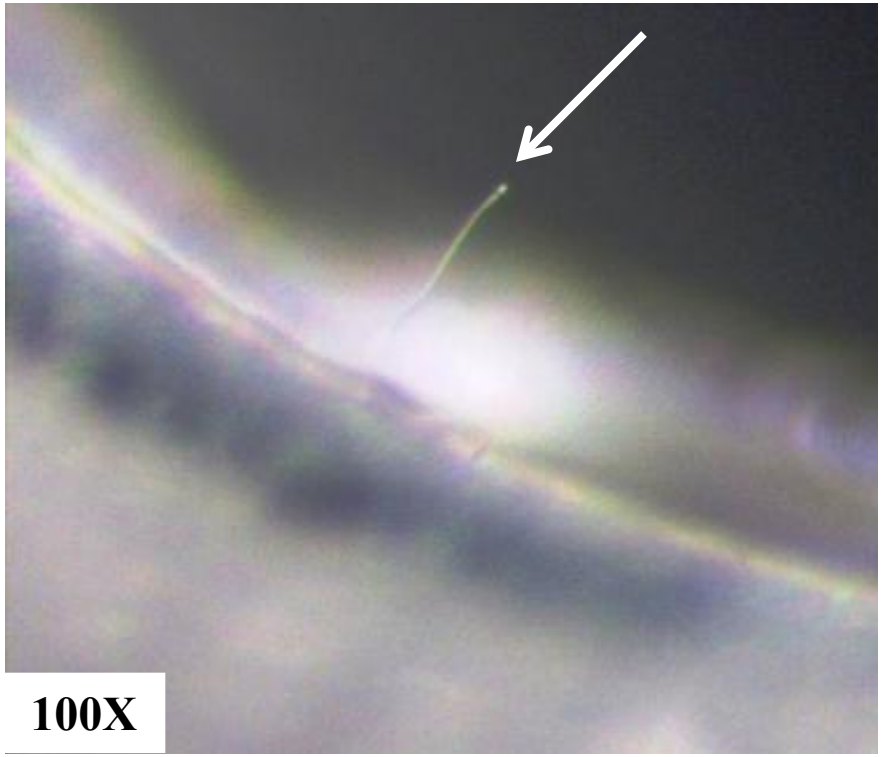
SEM Image at Lead Bend

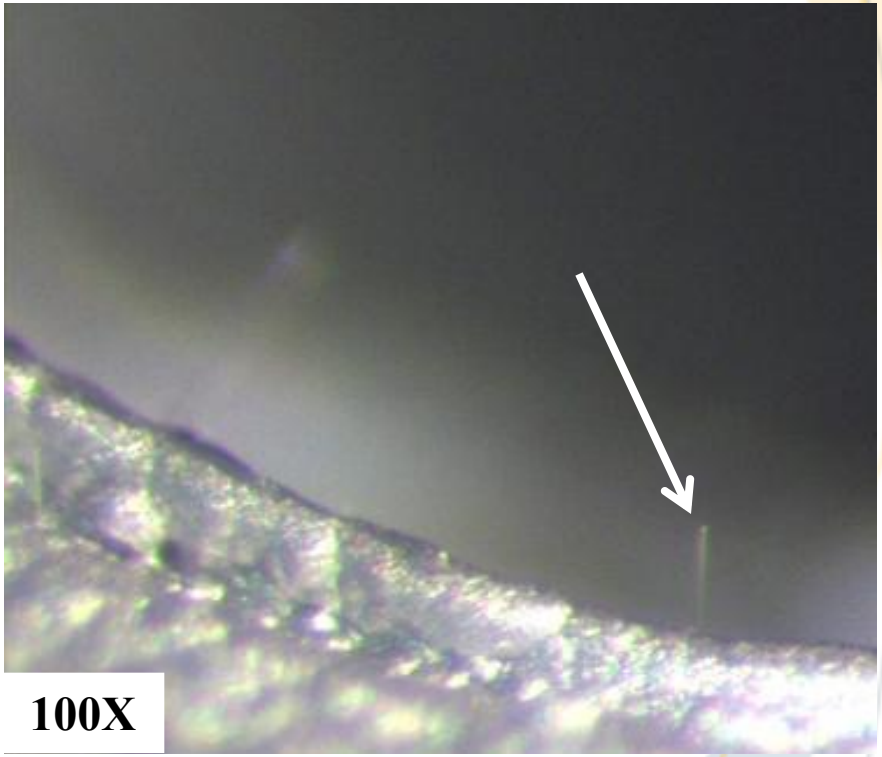


Ongoing Activity
"D-Sub Connector"



D-Sub Connector
Sn Whiskers on Jack-Screw threads





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- Return next year with an update!

Questions?