Assembly Cleanliness and Whisker Formation

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Abstract

This paper describes the results of a whisker formation study on SAC305 assemblies, evaluating the effects of cleanliness and lead-frame materials in room temperature/high humidity (25°C/85%RH). Cleaned and contaminated small outline transistors were soldered to custom designed test boards using Sn3Ag0.5Cu (SAC305) solder. Before assembly components were divided into two groups. The first group was cleaned using the method developed in this study. The level of contamination was 10 times below typical acceptable industry level and did not exceed 0.062 µg/cm^2 (0.4 µg/in^2) Cl. The second group was contaminated with NaCl. The piece part level of chlorine contamination 0.465 µg/cm^2 (3 µg/in^2) was selected to be within the industry levels encountered (no standards exist). After assembly, all the boards were cleaned, and half of them were re-contaminated to a level of at least 1.56 µg/cm^2 Cl (10.1 µg/in^2). Whisker length, diameter, and density were measured. Detailed metallurgical analysis on components before assembly and on solder joints before and after testing was performed. It was found that whiskers grow from solder joint fillets, where the thickness is less than 25 µm. The influence of lead-frame material, cleanliness, and environment on whisker characteristics is discussed. Assembly contamination is an important consideration for whisker growth in harsh service environments.

Introduction

Due to the increased use of Pb-free, commercial-of-the-shelf (COTS) components in high reliability applications, the risk of system failure due to tin whiskers has increased. As the SnPb componet obsolescence is being managed, the high reliablity industries are also investigating the effects of SnPb solders, which are more prevalent in dual use applications. Further, many of these high reliablity applications are required to survive harsh to severe operating conditions which may promote whisker growth, including high temperatures and high humidities, high vibration and thermal shock.[1] Tin whisker mitigation strategies have therefore been adopted by the aerospace and defence indusrty.[2]

Local compressive forces within the solder joint are thought to be responsible for the nucleation and growth of tin whisker.[3] Figure 1 provides a schematic representation of some of the compressive forces, experienced by a solder joint or a component lead, which may lead to the growth of a whisker. It is believed that the tin whisker provides a means of relieving the stress built up within the material due to the compressive forces. When exposed to high humidity levels, as in this study, it has been shown that the Sn reacts with oxygen to form Sn oxides, SnO or SnO_2, resulting in a volume expansion.[4] This expansion provides the local compressive force acting on the bulk solder.

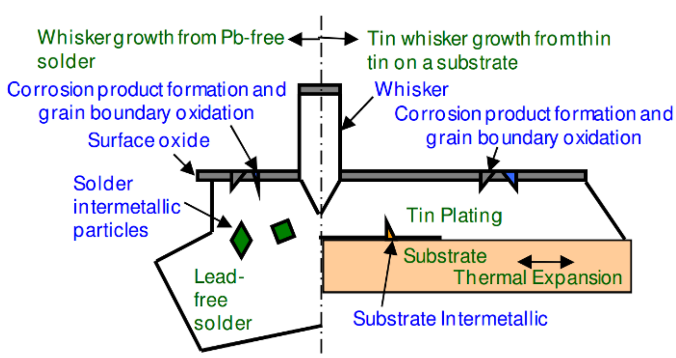


Figure 1: Source of compressive stress contributing to whisker growth[5]

Additionally, the intermetallic compounds (IMC) which form in the bulk of SAC solders may also percipiate whisker growth. For example, it has been found that Ag_3Sn particles at the surface of the solder become sourounded by oxidation zones after exposure to high temperature, high humidity (85°C/85%RH).[3] The differing galvanic potentials of the constituent particles making up the SAC solder joint make it more suseptable to localized corrosion. This oxide layer begins to form at the surface but may continue to propogate along the IMC particle and dendritic grain boundaries through the bulk of the solder.

In this study, assemblies where exposed to ambient temperature and high humidity (25°C/85%RH) over a long period of time. In this work, the internal stresses generated within the solder joint are believed to be mainly a result of corrosion or oxidation conditions. The degree to which lead frame material and cleanliness levels affect the degree of oxidaion and whisker growth are studied.

Oberndorff et al. found that fewer and shorter whiskers grew on Sn plated components assembled with SnPb than on loose components when exposed to high temperature, high humidity conditions (60°C/93% RH).[6] The opposite was found to be true for Pb-free assemblies. During assembly using a SnPb solder, the solder is expected to wet a portion of the lead and form a filet while the rest of the lead maintains its original plating material (Figure 2a). Due to the higher reflow temperatures used to assemble SAC solders, the electroplated Sn on the lead frame melts. The solder is therefore likely to completely wet and cover the lead (Figure 2b).[3]

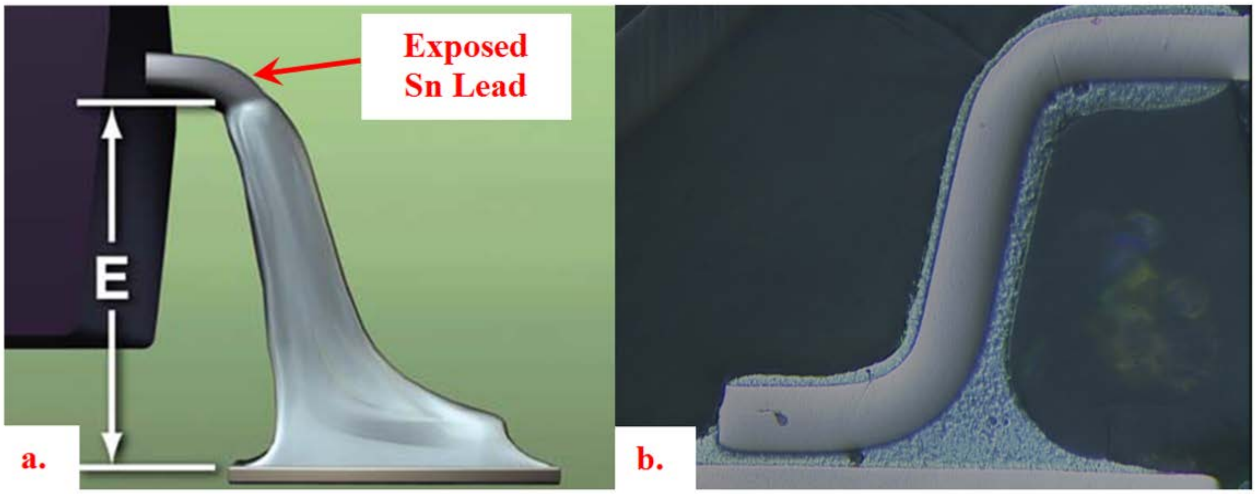


Figure 2: (a) Schematic for a typical solder joint of a leaded component using SnPb solder[7], (b) cross section showing solder joint formed with Pb-free solder

It has been previously proposed that covering a lead completely with SnPb solder would provide some mitigation for whisker growth.[2] The same however can not be said for SAC solder alloys, where, it has been found that whiskers grow directly from the solder.[8] The rough surface produced by SAC alloys, through the dendritic growth of βSn resulting in surface shrinkage voids, provide locations to entrap contaminates. It may, for example be difficult to clean unreacted flux from the rough surface of a solder joint during production. When exposed to high humidity, it is also possible that these shrinkage voids provide locations for moisture to condense.

This work is part of a larger, multi year test and modeling study funded by the Stragegic Environmental Reaserach and Development Program (SERDP) in which various test conditions, contamination conditions and alloy materials where investigated. The goal is to improve the tin whisker mitigation stratedgies within aerospace and defense electronic equipment.[5]

Experimental Set Up

Test vehicle

The test vehicle (Figure 3), custom designed by BAE Systems and Celestica for the purpose of investigating tin whisker growth[9] on lead-free solder assemblies, is a 6 cm x 6 cm x 2.36 mm double sided epoxy board with an immersion tin (ImmSn) finish. The size of this test vehicle was developed in order to easily fit into the chamber of an SEM, and to scan the full range of components without the need for repositioning. This allows for the assembly to be exposed to a variety of test environments and inspected periodically without the need for disassembly or cutting. While test protocols exist for the evaluation of components (i.e JESD201[10]), this test vehicle was developed in order to test the propensity of an assembly to grow whiskers under different conditions, evaluating a variety of variables.

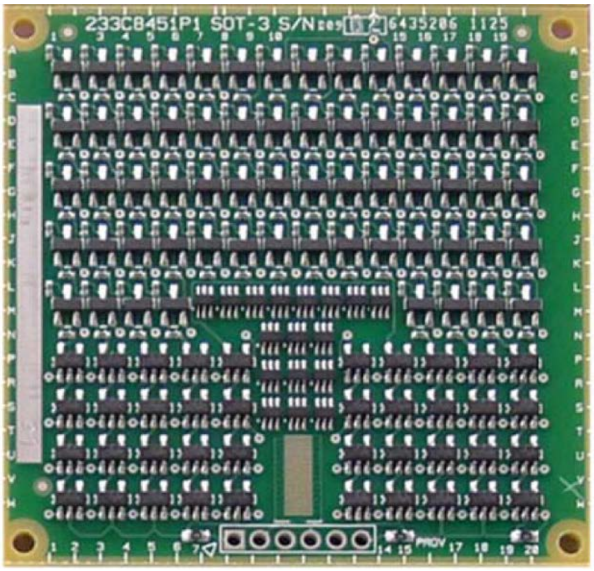


Figure 3: Test Vehicle

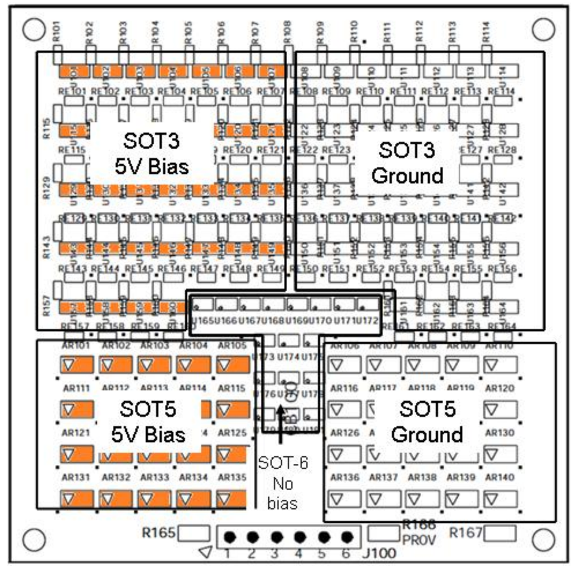
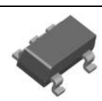


Figure 4: Test Vehicle Electrical Schematic

The test vehicle was designed in order to include enough components of each type (Table 1) for a statistically valid number of leads for the purpose of inspection. Additionally, the test vehicle was designed to accommodate two bias parameters. Figure 4 shows the electrical schematic of the test vehicle. Half of the SOT3 components and half of the SOT5 components are connected to an input power of 5V, the other half are connected to ground. The SOT6 components are not connected. The bias conditions are summarized in Table 2. While the boards were powered up during this testing, the bias conditions are not expolored in this paper. This may be evaluated as part of future work.

Table 1: Component List

Part		Part Designation	Lead Frame Material	Lead Finish	# Components /board	# Leads /board
	2N7002 (SOT23-3)	SOT3	Alloy 42	Matte Sn	64	192
	NC7S08M5X (SOT23-5)	SOT5	Cu194	Matte Sn	40	200
	2N7002DW-7-F (SOT363)	SOT6	Alloy 42	Matte Sn	17	102

Alloy 42 = Fe 42Ni
Cu194 = Cu 2.1-2.6Fe 0.015-0.15P 0.05-0.2Zn

Table 2: Bias Conditions on Test Vehicle[11]

Component	Applied Power	Lead	Bias1	Bias2
SOT3	ground	All	0	0
	5V	1	5	5
		2	5	0
		3	5	5
SOT5	ground	All	0	0
	5V	1	5	0
		2	5	5
		3	5	0
		4	5	0
		5	5	5
SOT6	no connect	All	0	0

Assembly

The test vehicle was assembled as part of a panel (Figure 5) which included 4 of the boards described above (SOT board) as well as two other board types: a BGA board (not populated in the image) and a QFP board. The panels were assembled at Celestica between August 9-17, 2011, using a SAC305 solder paste

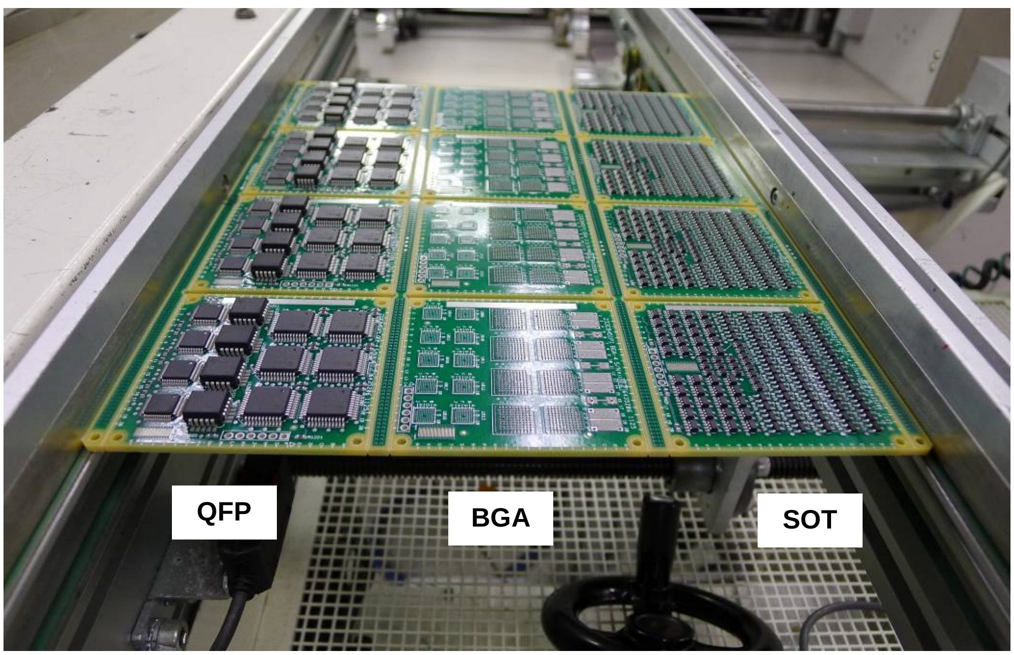


Figure 5: Test Vehicle Panel Assembly including QFP, BGA and SOT boards

Cleaning Methodology

In this work, cleaning and contamination was performed at both the component level and on the final assembly. The test boards were divided into four groupings; clean components – clean assemblies, contaminated components – clean assemblies, clean components – contaminated assemblies and contaminated components – contaminated assemblies.

<u>Component Cleaning</u>

The component cleaning procedure was developed using methodology common to extraction of ionic contaminates for evaluation by ion chromatography. Component cleaning procedure occurred before assembly. The components were immersed in a solution of 10% IPA/ 90% de-ionized (DI water) (by volume) with a sealed KPak® bag. These KPak® bags were then placed in a steam bath at 80°C for 40 minutes followed by 40 minutes of agitation on a shaker table. These two steps were repeated. The component where then drained of the IPA solution through a mesh and dried in a oven at 60°C for 10 minutes. The components where then tape and reeled for assembly. After cleaning, the components had a typical level of contamination which is 10 times below the acceptable level.[3] The resultant cleanliness levels are given in Table 3 and Table 4.

Table 3: Part Contamination Levels after Cleaning

Component	Total Inorganic Anions (µg/in²)	Total Organic Anions (µg/in²)
SOT3	0.4	3.3
SOT5	0.3	0.0
SOT6	0.2	3.5

Table 4: Concentration of Inorganic Anions after Cleaning

Component	Floride (µg/in²)	Chloride (µg/in²)	Nitrite (µg/in²)	Bromide (µg/in²)	Nitrate (µg/in²)	Sulphate (µg/in²)	Total Inorganic Anions (µg/in²)
SOT3	0.0	0.0	0.0	0.0	0.2	0.2	0.4
SOT5	0.1	0.0	0.0	0.0	0.1	0.0	0.3
SOT6	0.1	0.0	0.0	0.0	0.1	0.0	0.2

Assembly Cleaning

All assemblies, with clean components and with contaminated components, where washed after assembly. This was done using an in-house production cleaning process designed to remove flux residue for high reliability products.

Contamination Method

Component Contamination

Component contamination occurred prior to assembly using a 166ppm NaCl solution in DI water. Components were placed in the solution which was then brought to 35°C (Figure 6) for four minutes and periodically agitated after which the solution was poured through a mesh. The components where then dried in an oven at 60°C for 10 minutes. The components were then tape and reeled, separate from the cleaned components, for assembly. The resultant contamination levels are given in Table 5 and Table 6.

Table 5: Part Contamination Levels after Contamination

Component	Total Inorganic Anions (µg/in²)	Total Organic Anions (µg/in²)
SOT3	1.9 - 2.3	0.0
SOT5	8.7	0.0
SOT6	7.4	0.0

Table 6: Concentration of Inorganic Anions after Contamination

Component	Floride (µg/in²)	Chloride (µg/in²)	Nitrite (µg/in²)	Bromide (µg/in²)	Nitrate (µg/in²)	Sulphate (µg/in²)	Total Inorganic Anions (µg/in²)
SOT3	0.1	1.7 – 2.2	0.0	0.0	0.0	0.0 - 0.1	1.9 - 2.3
SOT5	0.3	6.7	0.0	0.0	0.0	0.7	8.7
SOT6	0.1	7.2	0.0	0.0	0.1	0.1	7.4

Figure 6: Components in Contamination

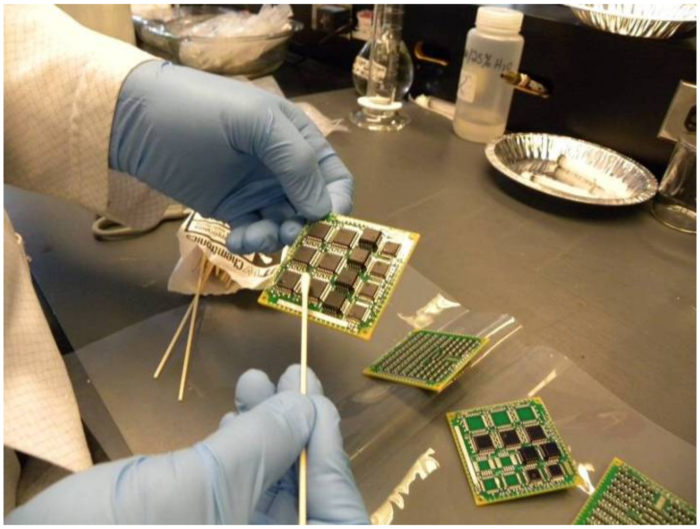


Figure 7: Excess Contamination Removed From Assembly

Assembly Contamination

The post assembly contamination was performed using a 160 ppm NaCl solution in DI water. The assemblies were immersed in this solution and agitated for 30 minutes. The assemblies were removed, any fluid which was beading on the component body was removed using a cotton swab (Figure 7), and placed in an oven and baked at 85°C for one hour.

Table 7: Contamination Levels

Component Condition		Assembly Condition		Labeling Convention
Condition	**Level (µg/in^2)**	**Condition**	**Level (µg/in^2)**	
Clean	< 0.4	Clean	N/A	0-0
Contaminated	2-8	Clean	N/A	1-0
Clean	< 0.4	Contaminated	> 10	0-1
Contaminated	2-8	Contaminated	> 10	1-1

Ambient Temperature High Humidity Long Term Testing

Prior to exposing the assemblies to the various environments, the assemblies were inspected and characterized by cross-sectioning. This has been previously reported.[5] Of note, Chloride contamination was found to be trapped within the solder. This indicates that the component level contamination resulted in some entraped contaminates and potentially lead to corrosion within the solder.

Chamber Conditions

Assemblies were then placed in a temperature and humiditiy chamber (Figure 8 and Figure 9). The samples were all connected to a power supply set at 5V. The chamber was set to run at 25°C and 85%RH. All precaution was taken to prevent condensation..

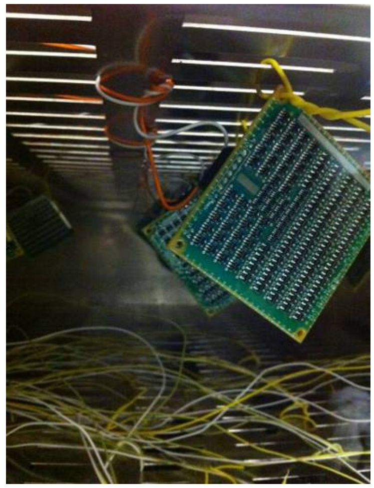


Figure 8: Samples in Temperature/Humidity Chamber

Figure 9: Temperature/Humidity Chamber

Whisker Inspection

JESD201 and JEDEC Standard No. 22-A121A[12] provide a protocol for examining whiskers. While they were writen with the intention of evaluating whiskers on unassembled components, many of the principles have been utilised in this study. The inspection of whiskers was performed at Celestica using a Hitachi S-3000 SEM in variable pressure mode, at a pressure of 25Pa and an acceleration voltage of 20kV. The results in this paper represent the final inspection performed on samples exposed to this particular environment and was perforemed after 16,000 hours of total test time and 12,000 hours from the last inspection interval. Table 8 summarises the quantity of whiskers both counted and measured, of each component type. Only whiskers which exceeded 10µm where measured.

Table 8: Total # Whiskers Inspected

Component	Lead Frame Material	# Whiskers Counted	# Whiskers Measured
SOT3	Alloy 42	134	7
SOT5	Cu194	4428	457
SOT6	Alloy 42	160	11
	Total	4754	475

Cross Sectioning

Components were cut from the test vehicle and mounted in epoxy for cross-sectioning. Each cross-section was ground and polished through the following sequence: 500 and 1200 grade SiC paper, polishing with 6 µm and 1 µm DiaPro diamond suspensions (Struers), and an oxide polish (Struers' OP-S). Optical microscopy was performed using a Nikon Measurescope

MM-11. Prior to SEM analysis, the samples were gold coated using an Polaron SC7640 Sputter Coater. SEM microscopy was performed using a Hitachi S-4500 and Hitachi S-3000N with the following EDX systems: Oxford and ThermoScientific respectively.

Results and Discussion

SOT3

After 16000 hours of exposure at ambient temperature and high humidity assemblies built with clean components then further cleaned after assembly exhibited no whisker growth. Only one whisker was observed on SOT3 components when contaminated components were used and the assembly was cleaned prior to exposure, and this whisker did not exceed 10µm. Contaminated assemblies, both with clean and with contaminated components exhibited more whisker growth on SOT3s. The contaminated assembly built with clean components resulted in the most whiskers at 117, however only two measured longer then 10µm. On the other hand, contaminated assemblies with contaminated components produced 16 whiskers in total on SOT3, however 5 were longer then 10µm and one reached a total length of almost 83µm.

Table 9: Summary of Results on SOT3 after 16000 hrs at 25°C/85%RH

Cleanliness	Components / Components w Whiskers	% Components w Whiskers	Leads / Leads w Whiskers	% Leads w Whiskers	Total Whiskers	Total Measured	Longest Whisker (µm)
0-0	48	0	144	0	0	0	0
	0		0				
1-0	48	2.1	144	0.01	1	0	0
	1		1				
0-1	48	25	144	12.5	117	2	30.6
	12		18				
1-1	48	14.6	144	6.9	16	5	82.9
	7		10				

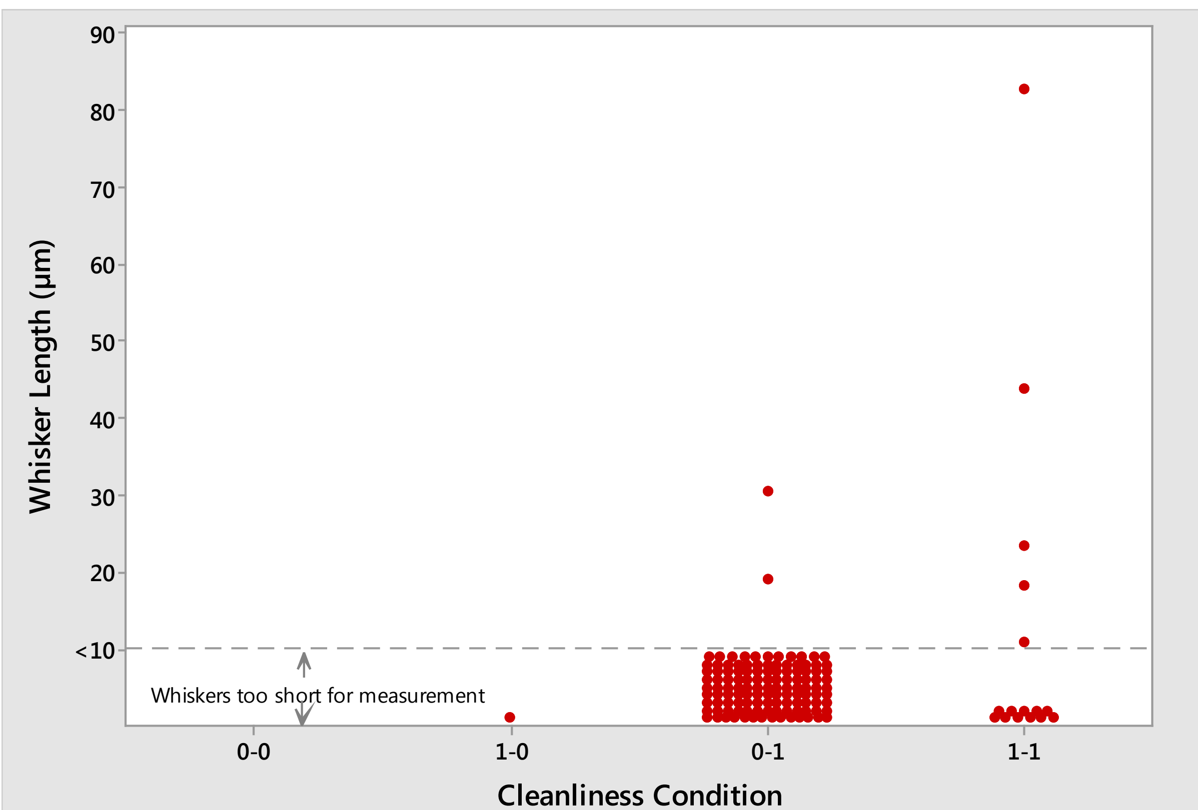


Figure 10: Length of Whiskers on SOT3 after 16000 hrs at 25°C/ 85% RH

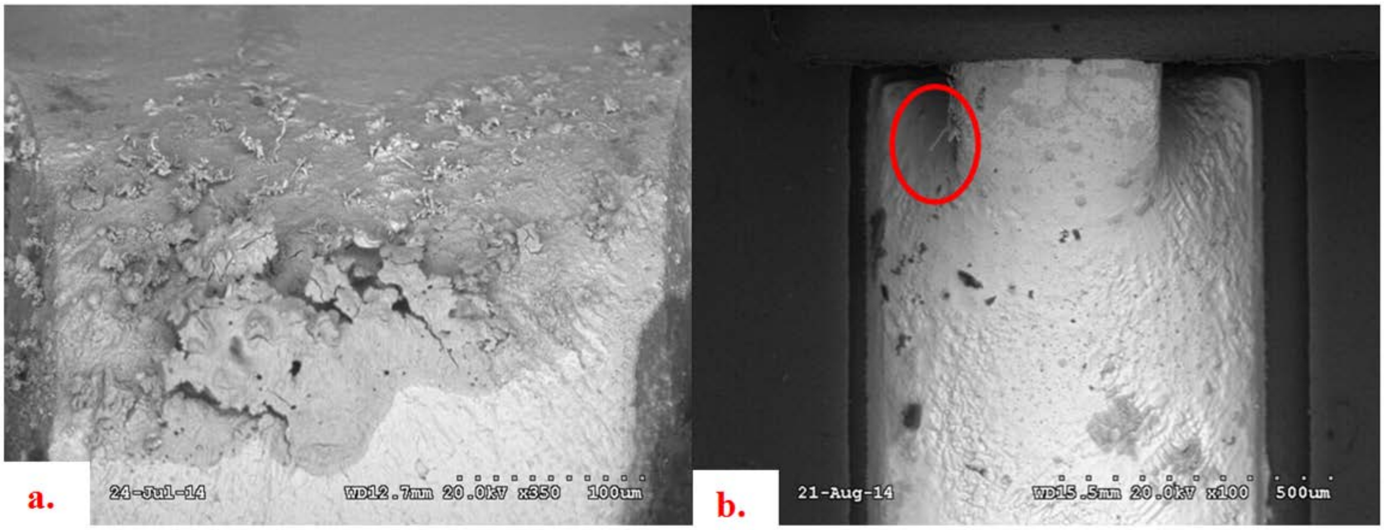


Figure 11: SOT3 after 16,000 hours at 25°C/85% RH. Contamination condition 0-1 (a) showed more whiskers than contamination condition 1-1 (b) however they were generally shorter

Whisker growth on the SOT3 components directly correlated with the degree of oxidation observed (Table 10). No oxidation was visible on the assemblies built with clean components and then cleaned again prior to exposure. Consequently no whiskers were observed. A small amount of oxidation occurred when contaminated components where used, and the assembly was cleaned prior to exposure, resulting in one very short whisker. Contaminated assemblies showed a greater degree of oxidation and resulted in the formation of whiskers; both normal and hollow shaped whiskers were observed. Figure 12 shows oxidation forming around an intermetallic compount (IMC) which is likely the result of differing chemical potentials between the bulk βSn and the IMC structures. A whisker is found to have formed near by. Figure 13 shows a whisker growing from an area of high oxidation.

Table 10: Visible Oxidation and Resulting Whiskers on SOT3 after 16,000 hrs at 25°C/85%RH

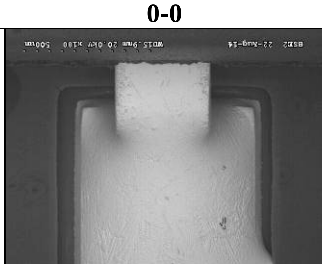
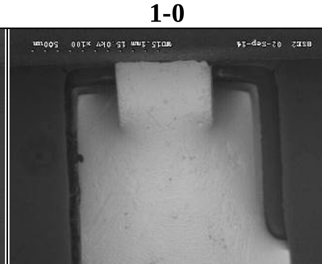
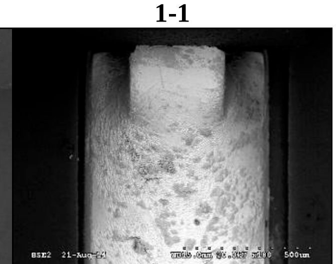
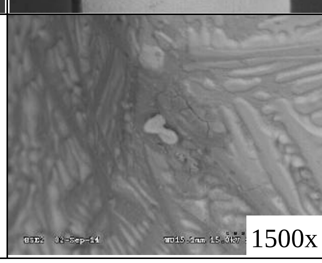
	0-0	**1-0**	**0-1**	**1-1**
100x				
Higher Mag.		 1500x	 3000x	 2500x

Figure 12: Oxidation occurring around IMC on SOT3 with a contamination level of 1-1

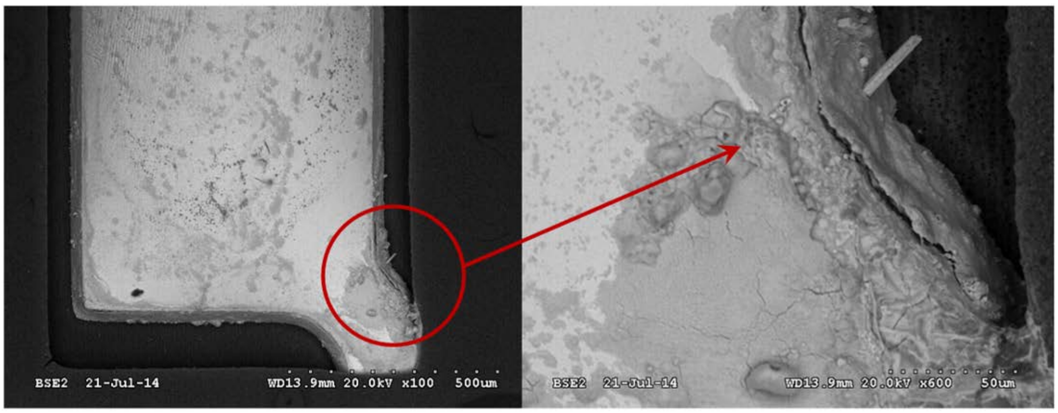


Figure 13: Whisker growing near site of oxidation on SOT3 at contamination condition of 0-1

SOT5

SOT5s, which have lead frames of Cu194, exhibited the most whisker growth of the three component types. Cleaned assemblies, both with clean and with contaminted components showed some whisker growth, a total of 6 and 27 whiskers respectively, however none where longer then 10µm. Contaminated assemblies, both with clean and with contamined components, exhibited a great deal of whisker growth with over 90% of the leads exhibiting some degree of whiskering. The most whiskers were observed on the contaminated assembly with contaminated components, however the longest whisker was observed when clean components were used.

Table 11: Summary of Results on SOT5 after 16,000 hrs at 25°C/85%RH

<table>
<tr><th rowspan="2">Cleanliness</th><th>Components</th><th rowspan="2">% of Components w Whiskers</th><th>Leads</th><th rowspan="2">% of Leads w Whiskers</th><th rowspan="2">Total Whiskers</th><th rowspan="2">Total Measured</th><th rowspan="2"># w Varied Diameter</th><th rowspan="2">Longest Whisker (µm)</th></tr>
<tr><th>Components w Whiskers</th><th>Leads w Whiskers</th></tr>
<tr><td rowspan="2">0-0</td><td>16</td><td rowspan="2">6.2</td><td>80</td><td rowspan="2">1.2</td><td rowspan="2">6</td><td rowspan="2">0</td><td rowspan="2">0</td><td rowspan="2">0</td></tr>
<tr><td>1</td><td>1</td></tr>
<tr><td rowspan="2">1-0</td><td>16</td><td rowspan="2">31.2</td><td>80</td><td rowspan="2">6.2</td><td rowspan="2">27</td><td rowspan="2">0</td><td rowspan="2">0</td><td rowspan="2">0</td></tr>
<tr><td>5</td><td>5</td></tr>
<tr><td rowspan="2">0-1</td><td>16</td><td rowspan="2">100</td><td>80</td><td rowspan="2">91.2</td><td rowspan="2">2040</td><td rowspan="2">203</td><td rowspan="2">21</td><td rowspan="2">92.1</td></tr>
<tr><td>16</td><td>73</td></tr>
<tr><td rowspan="2">1-1</td><td>16</td><td rowspan="2">100</td><td>80</td><td rowspan="2">98.8</td><td rowspan="2">2355</td><td rowspan="2">254</td><td rowspan="2">38</td><td rowspan="2">80.7</td></tr>
<tr><td>16</td><td>79</td></tr>
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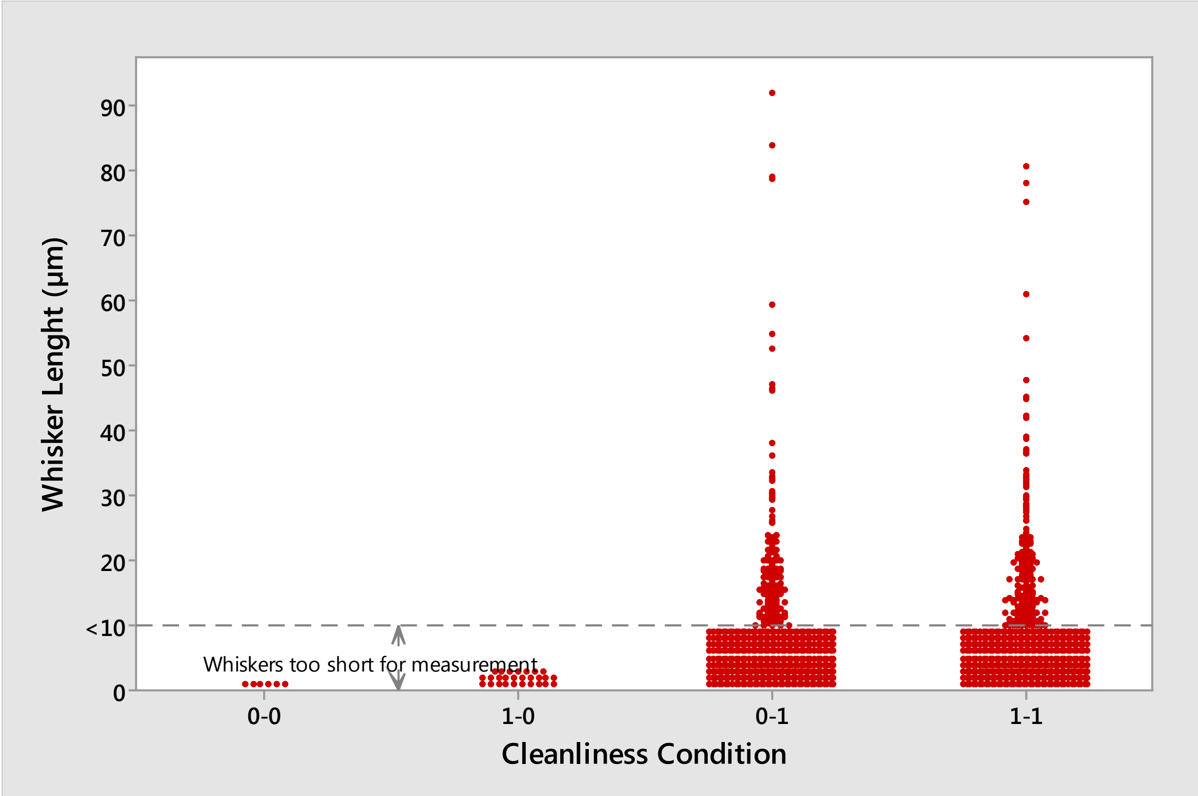
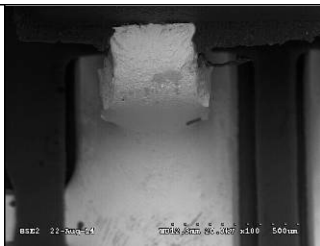
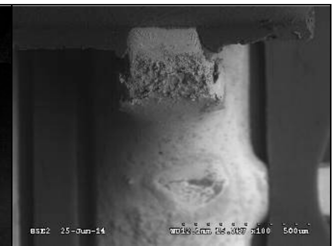
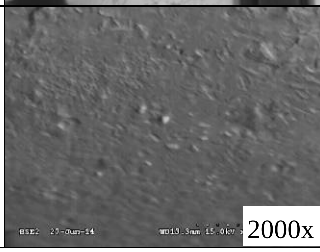
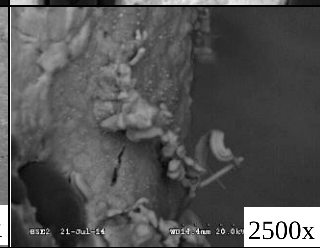
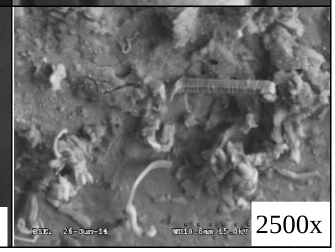


Figure 14: Length of Whiskers on SOT5 after 16,000 hrs at 25°C/ 85% RH

Table 11 provides a summary of the observed oxidation levels on SOT5 components. Similar to the results on the SOT3 components, SOT5 showed very little oxidation and whisker growth on cleaned assemblies, both with clean components and with contaminated components. Where whiskers did appear, they were very short. On clean assemblies built with contaminated components, there was some recrystalization of grains observed as well as a small amount of oxidation forming around IMC particles (Figure 15). When boards were contaminated (both clean and contaminated components) oxidation and consequentely whisker growth increased in both density and length. Every component that was part of the contaminated assembly subset experienced some degree of whisker growth as did over 90% of the leads. When long whiskers occur (Figure 16), they are very thin, approximately 0.1 to 0.4µm, and are not visible at magnifications of 250-300x (Figure 17). These extremely thin whiskers usually appear to be straight, but are sometimes kinked (Figure 18).

Both hollow and "normal" whiskers were observed after 16,000 hours of 85C/85%RH (Figure 19). Figure 20 is a schematic showing the relative location of each type of whisker; "normal" whiskers grow in locations L4, L3 and L1, hollow whiskers grow on L2, and L5.

Table 12: Visible Oxidation and Resulting Whiskers on SOT5 after 16,000 hrs at 25°C/85%RH

	0-0	1-0	0-1	1-1
100x				
Higher Mag.	 2000x	 1000x	 2500x	 2500x

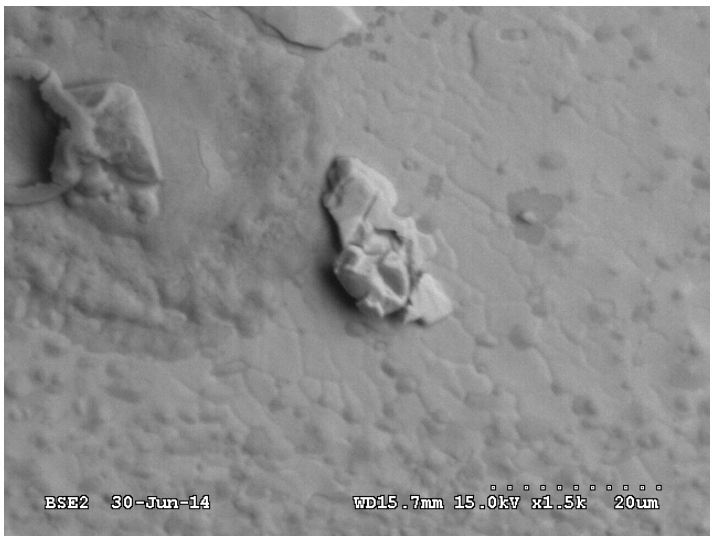


Figure 15: Recrystallized grain, oxidation occurring around IMC on SOT5, contamination condition of 1-0

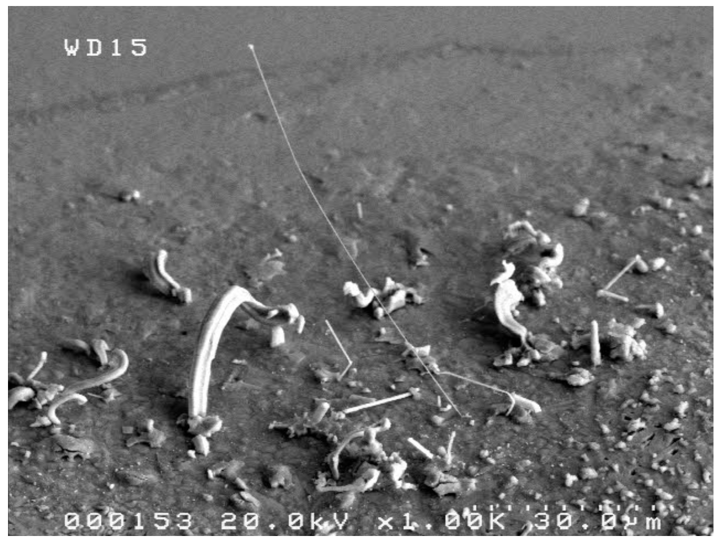


Figure 16: Long, thin whiskers (0.1- 0.4µm diameter) on SOT5 with a contamination condition 1-1

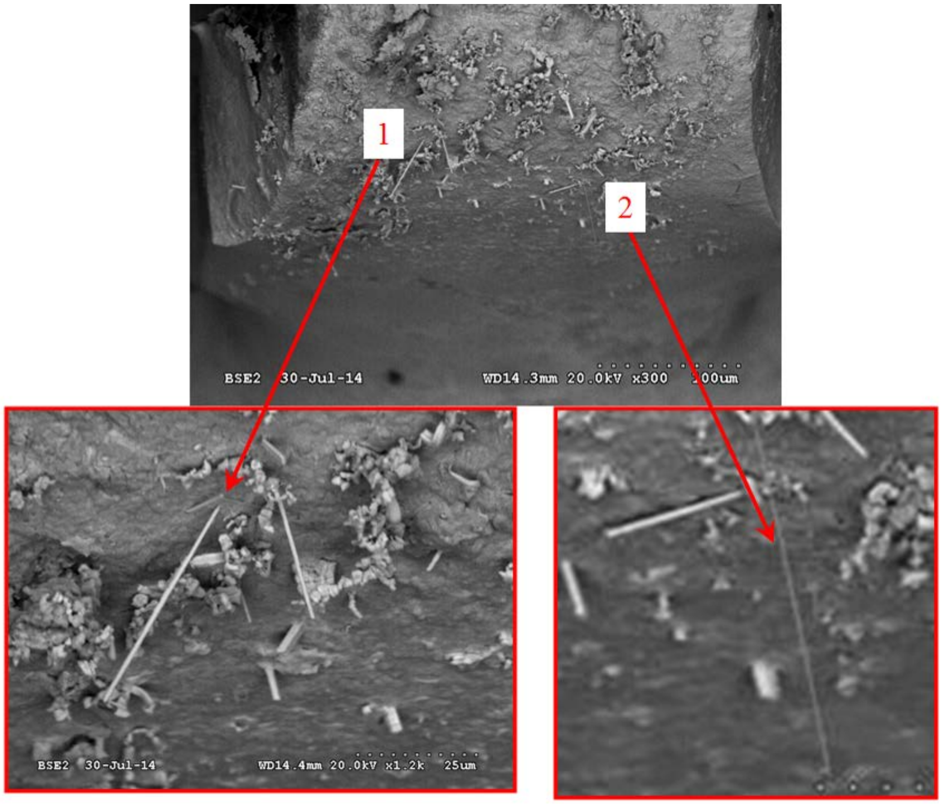


Figure 17: Very long, very thin whiskers on SOT5, contamination condition 1-1

Figure 18: Both straight (2) and kinked (1) long whiskers appear on SOT5 on SOT5, contamination condition 1-1

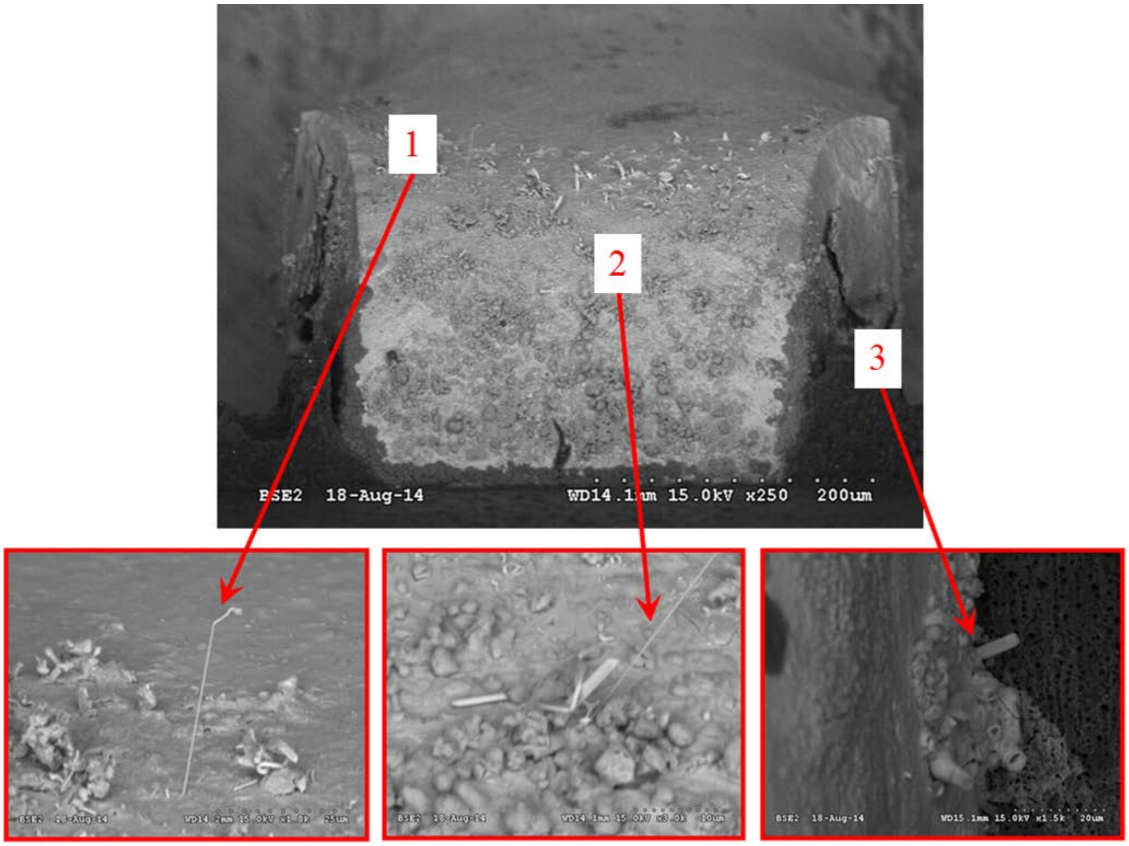


Figure 19: Whiskers of different dimensions growing from a SOT5, contamination condition 1-1 long, kinked whisker (1), very long, very thin whisker (2) and hollow whisker (3)

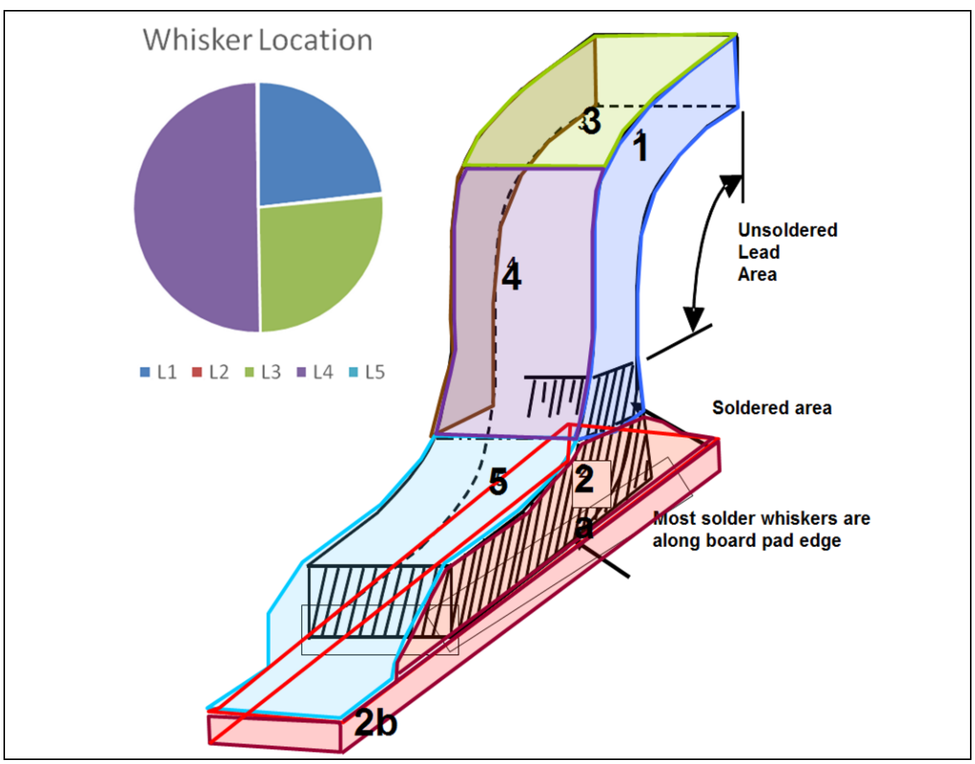


Figure 20: Schematic showing location of whiskers on a lead

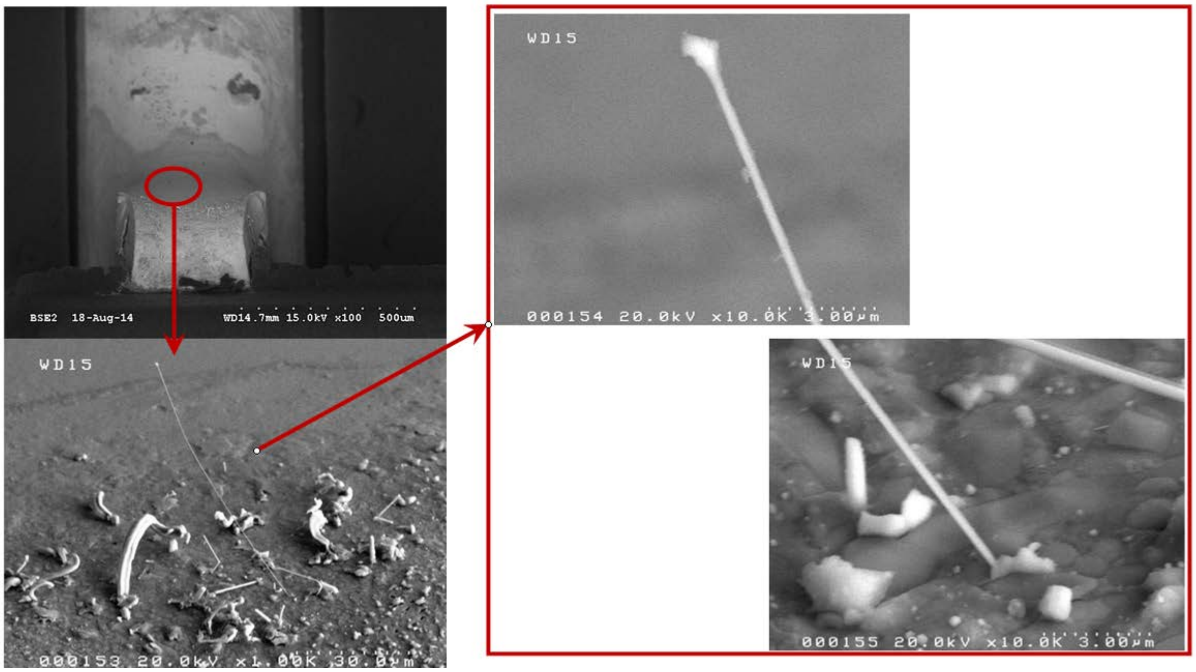


Figure 21: Whisker growing on SOT5 with contamination condition 1-1 after 16,000 hrs at 25°C/85%RH (Length – 80.7µm, Diameter – 0.3µm)

SOT6

SOT6 components on clean assemblies, exhibited very little whiskering with only one whisker growing on an assembly built with clean components and none when contaminated components where used. This one whisker did not exceed 10µm. The contaminated assemblies showed a significant amount of whiskering, with over 40% of leads exhibiting whiskers. The contaminated boards with contaminated components showed more whiskers with a total of 126, however with clean components longer whiskers where observed with a total of 7 exceeding 10µm.

Table 13: Summary of Results on SOT6 after 16,000 hrs at 25°C/85%RH

Cleanliness	Components / Components w Whiskers	% of Components w Whiskers	Leads / Leads w Whiskers	% of Leads w Whiskers	Total Whiskers	Total Measured	Longest Whisker (µm)
0-0	8	12.5	48	2.1	1	0	0
	1		1				
1-0	8	0	48	0	0	0	0
	0		0				
0-1	8	100	48	41.7	33	7	63.5
	8		20				
1-1	8	100	48	47.9	126	4	23.2
	8		23				

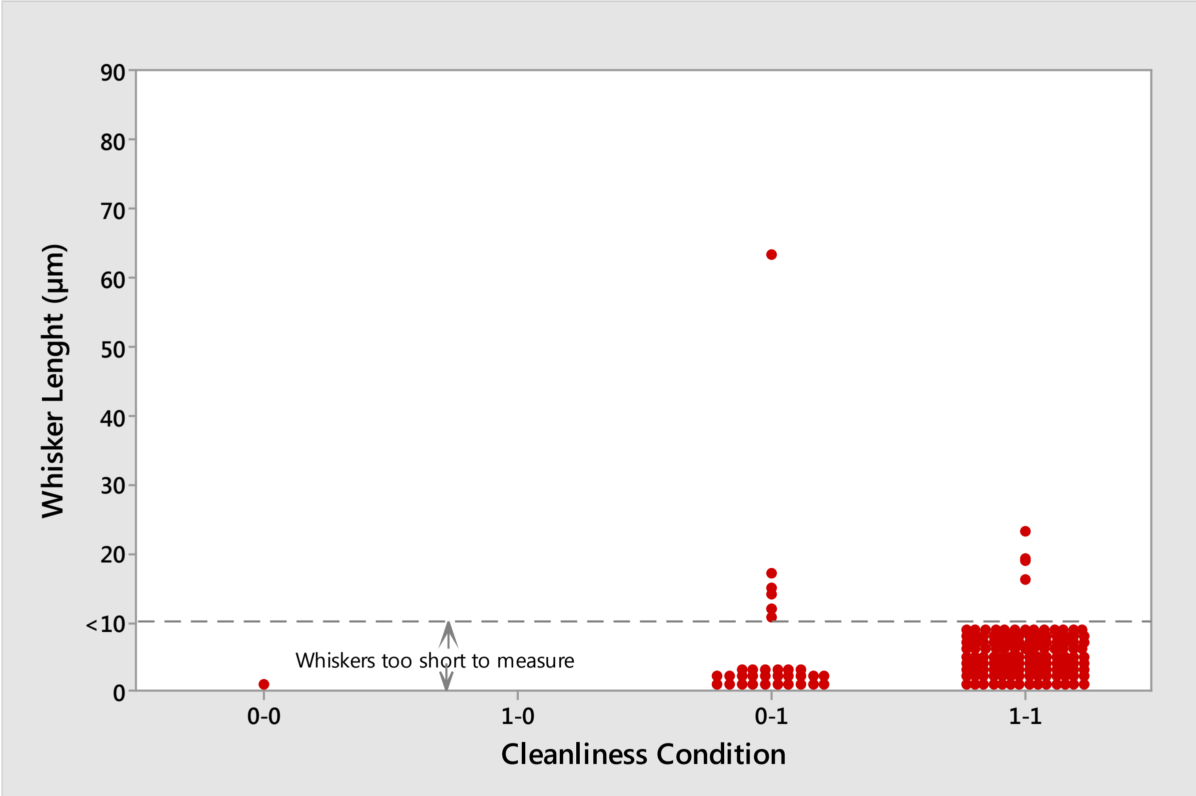
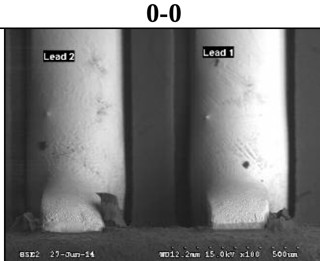
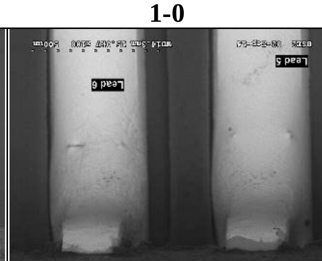
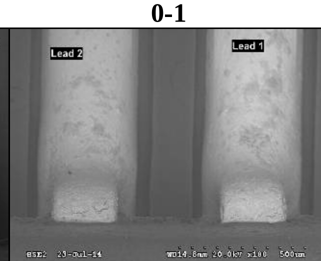
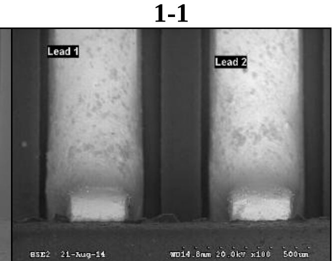
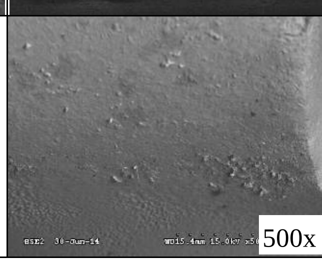
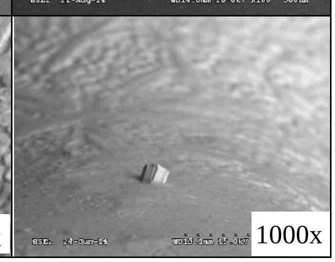


Figure 22: 7 Longest Whiskers on SOT6 after 16,000 hrs at 25°C/ 85% RH

Similar to the SOT3, the SOT6 leads are made from Alloy 42 leadframe material plated with matte Sn. The amount, and length of whisker growth correlates to the degree of oxidation observed on the lead (Table 14). Similar to the SOT5s, most "normal" whiskers were found in locations L4, L3 and L1, while the hollow whiskers could be found L2 and L5 (Figure 23). In general, where there was a high degree of oxidation; contaminated assemblies – there appeared many short whiskers (Figure 24). These whiskers often appeared at the site of the oxidation (Figure 25).

Table 14: Visible Oxidation and Resulting Whiskers on SOT6 after 16,000 hrs at 25°C/85%RH

	0-0	1-0	0-1	1-1
100x				
Higher Mag.				

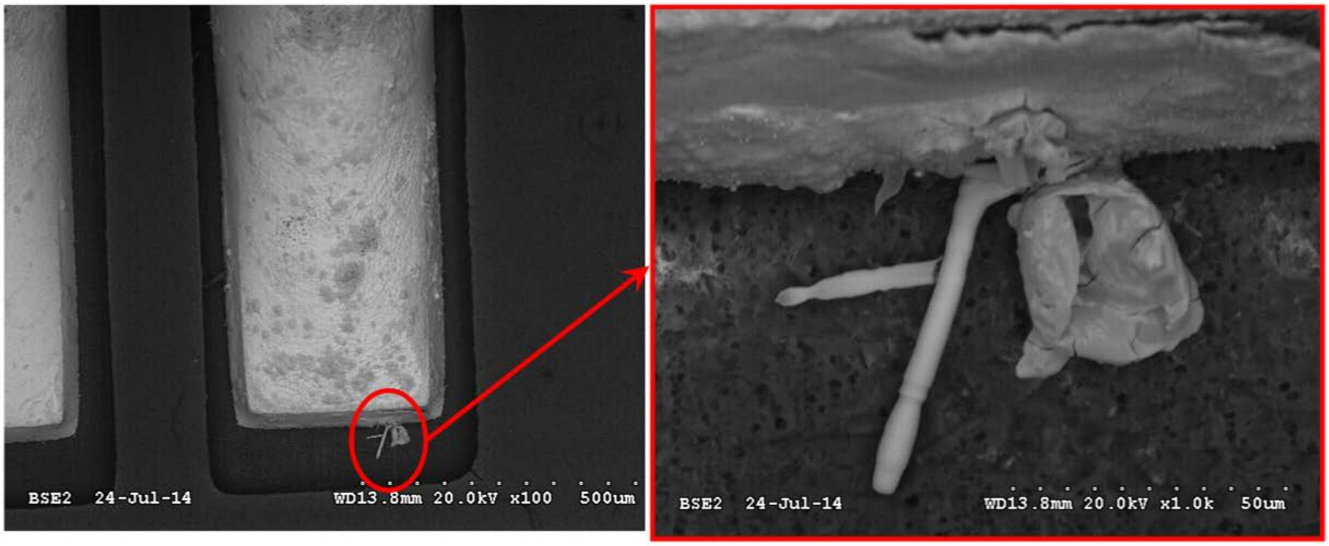


Figure 23: Hollow whiskers growing on SOT6, contamination condition 0-1 in location L2

Figure 24: Many short whiskers SOT6, contamination condition 1-1

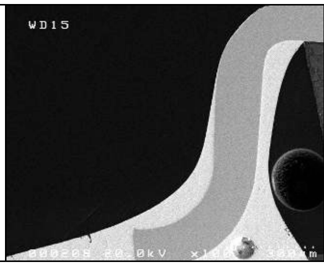
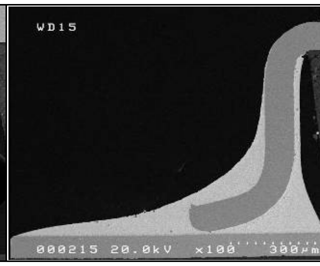
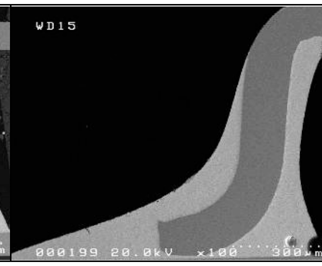
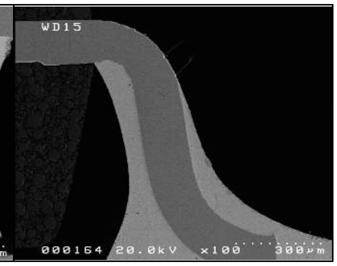
Figure 25: Whiskers at site of oxidation SOT6, contamination condition 1-1

Cross Sections

Further analysis of the test samples was performed by cross sectioning. In this study SOT5s, made from Cu194, was the focus as they exhibited the highest degree of whisker growth. Samples that where assembled using clean components, and then further cleaned after assembly (contamination condition 0-0) had no visible oxidation either at the surface of the solder, or throughout the bulk (Figure 26). This corresponded to very little whisker growth, with no whiskers growing beyond 10µm. Cross sections of samples built with contaminated components but cleaned after assembly (contamination condition 1-0), showed little to no surface oxidation. There was however, corrosion visible in the bulk of the solder (Figure 27) which propogated through the interdendritic spaces. The formation of this oxide within the bulk may contribute to compressive stress which ultimately lead to whisker formation.[13]

Samples which were cleaned after assembly, both those assembled with clean components (0-1) and those with contaminated components (1-1) showed a significant degree of surface oxide formation (Figure 28). The amount and degree of whiskering also increased in direct correlation as seen in the whisker inspection results above. By analyzing the cross sections of these assemblies, it was also clear that the whiskers themselves experienced oxidation (Figure 29, Figure 30).

Table 15: Cross Sectional View of SOT5 after 16,000 hrs at 25°C/85%RH

	0-0	1-0	0-1	1-1
100x				

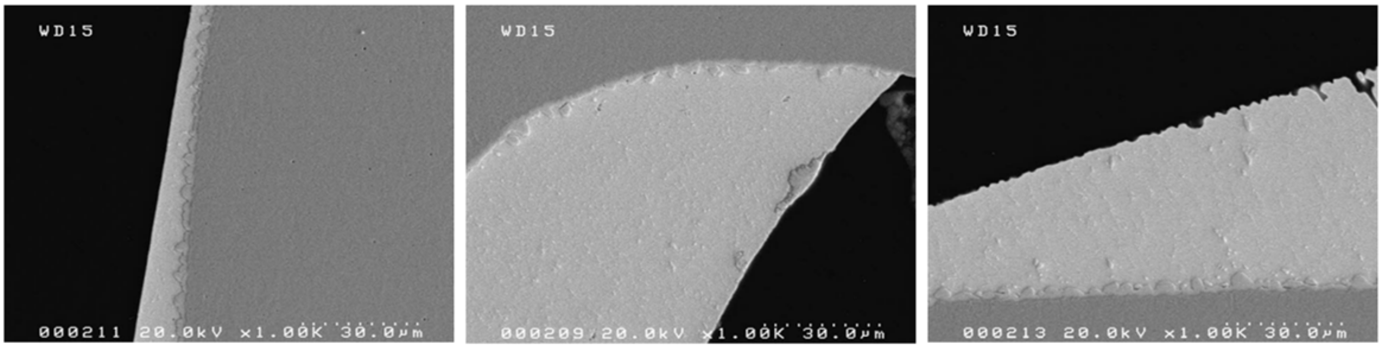


Figure 26: Little to no oxidation visible on SOT5 after 16,000 hrs at 25°C/85%RH with contamination condition 0-0

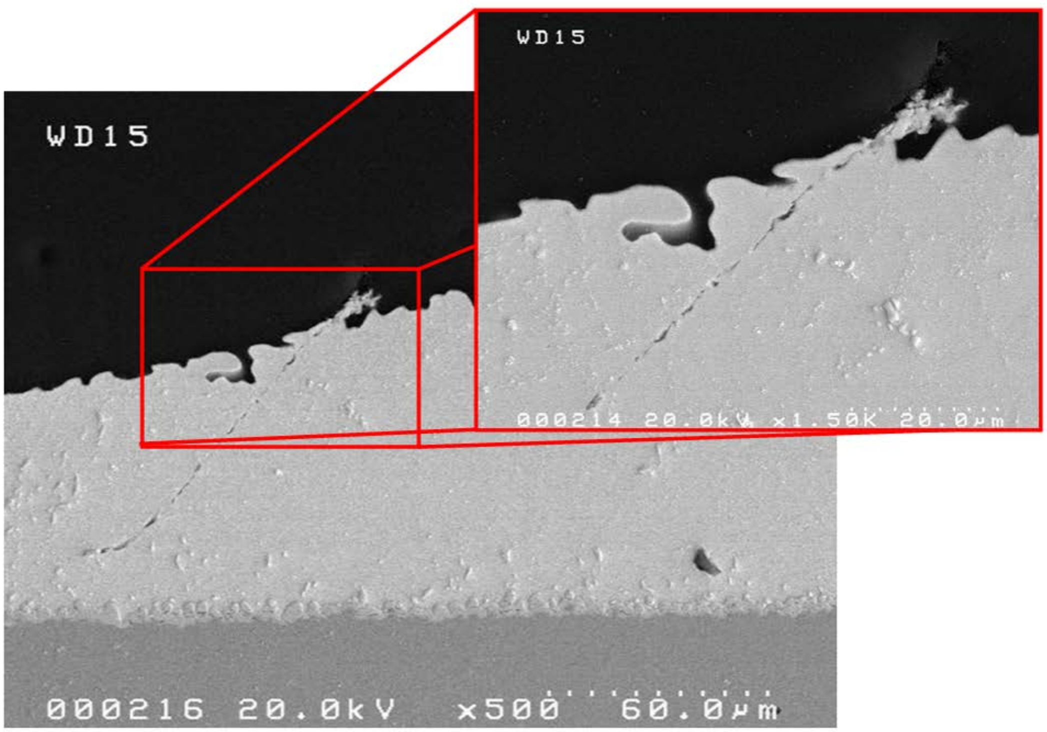


Figure 27: No surface oxidation, corrosion in interdendritic spaces within solder on SOT5 after 16,000 hrs at 25°C/85%RH with contamination condition 1-0

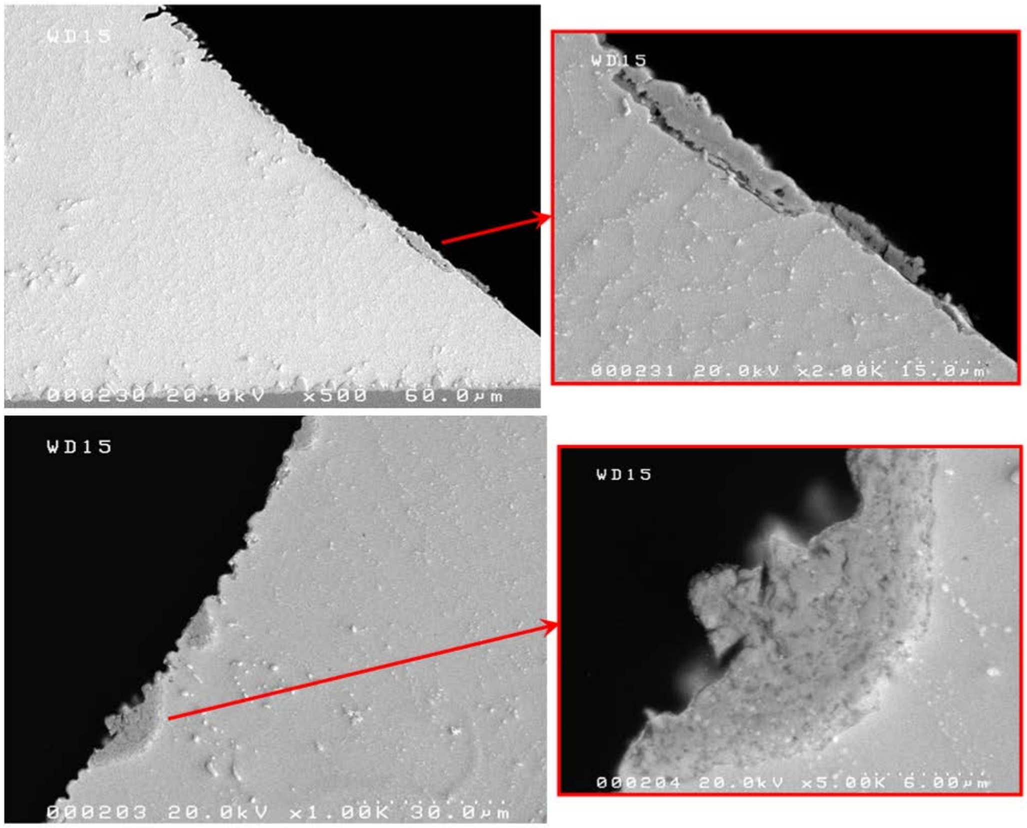


Figure 28: Significant surface oxidation on SOT5 after 16,000 hrs at 25°C/85%RH with contamination condition 0-1

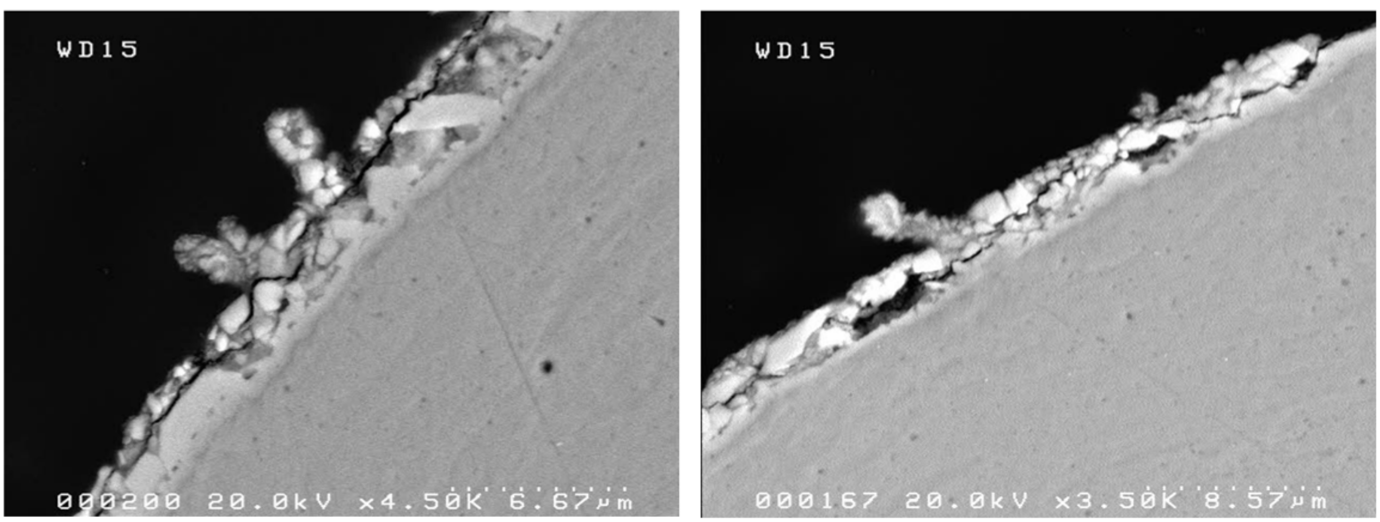


Figure 29: oxidized whiskers observed on SOT5 after 16,000 hrs at 25°C/85%RH with contamination condition 0-1

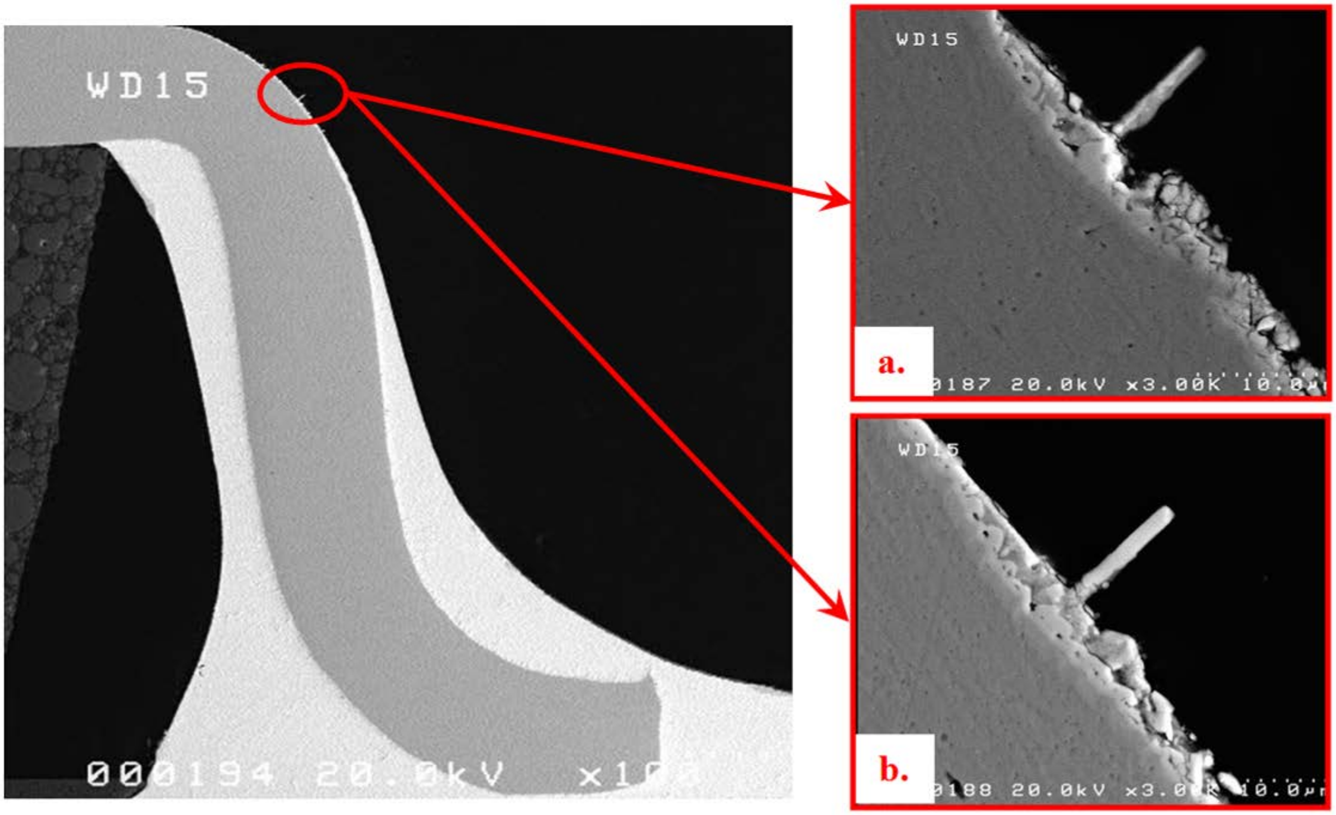


Figure 30: Oxidized whiskers observed on SOT5 after 16,000 hrs at 25°C/85%RH with contamination condition 1-1. Cross sectioning to successive planes, (a.) and (b.) illustrates the degree of oxidation through the whisker

Summary

After 16,000 hours of exposure to 25°C/85%RH, over a three year period, the effects of contamination of both components pre-assembly and of test vehicles after assembly were assessed.

Whisker growth was observed on all component configurations (SOT3, SOT5 and SOT6) however SOT5 with a Cu194 lead material experienced significantly more whisker growth, in terms of both density and length, than the SOT3 and SOT6 which have a base material of Alloy 42. On the assembled SOT5 components, a significant number of parts would fail the JESD201 piece part acceptence requirement for class 2, 40µm.[10] This acceptance criterea is designed to test the specific lead finish techolology or process of an unassembled component. While there is no current test for an assembled component, this criteria is provided for context.

Degree of whisker formation and length of the resultant whiskers appears to correlate directly to the amount of surface oxidation observed on the components. Significant surface oxidation occurred at the surface when test vehicles were contaminated after assembly (0-1 and 1-1). This assembly contamination level is within the currently acceptable industry standards. Little to no surface oxidation was observed when test vehicles were cleaned post assembly (0-0 and 1-0). The cleaning process used in this test was an in-house production cleaning process designed to remove flux residue for high reliability products.

Cross sectioning revealed some degree of oxidation within the bulk solder as a result of contaminated components . The contamination levels for component was chosen to be representative of 'as received' products. This indicates that post assembly cleaning may be insufficient to prevent corrosion of the sample. Samples which were assembled using contaminated components and cleaned after assembly (1-0) however did not result in any whiskers greater the 10µm or within the measurable range. Cleaning of components prior to assembly may provide further risk mitigation.

Future work

The influence of electrical bias was not evaluated in this study.

Acknowledgements

The authors would like to thank the Strategic Environmental Research and Development Program (SERDP) office for funding this reseach, André Dehaise for assisting in data analysis and Prakash Kapadia and Jie Qian for sample preparation and contaimination as well as analysis of contamination levels.

References

[1] GEIA-STD-0005-3: Performance Testing For Aerospace And High Performance Electronic Interconnects Containing Pb-Free Solder And Finishes

[2] GEIA-STD-0005-2: Standard for Mitigating the Effects of Tin Whiskers in Aerospace and High Performance Electronic Systems

[3] P.Snugovsky et al. "Whisker Formation Induced by Component and Assembly Ionic Contamination" in the Journal of Electronic Materials, Vol. 41, No. 2, 2012.

[4] A.Baated et al. "Effects of Reflow Atmosphere and Flux on Tin Whisker Growth of Sn-Ag-Cu Solder" presented at SMTAI, Chicago, Il, 2009

[5] S.J. Meschter et al. "SERDP Tin Whisker Testing: Low Stress Conditions" presented at International Conference on Solder Reliability, Toronto, Ontario, Canada, 2012.

[6] P. Oberndorff et al. "Humidity Effects on Sn Whisker Formation" IEEE Trans. Electron. Packag. Manuf.. 29, 4 (2006).

[7] IPC-A-610E-2010: Acceptability of Electronic Assemblies

[8] P.Snugovsky et al. "Whisker Growth on SAC Solder Joints: Microstructure Analysis" presented at International Conference on Solder Reliability, Toronto, Ontario, Canada 2008.

[9] H. McCormick et al. "Development of a Test Vehicle for the Study of Tin Whiskers" presented at International Conference on Solder Reliability, Toronto, Ontario, Canada 2010.

[10] JESD201 Environmental Acceptance Requirements for Tin Whisker Susceptibility of Tin and Tin Alloy Surface Finishes

[11] S.J. Meschter et al. "SERDP Tin Whisker Testing and Modeling: High Temperature/High Humidity Conditions" presented at International Conference on Solder Reliability, Toronto, Ontario, Canada, 2013.

[12] JESD22-A121A Test Method for Measuring Whisker Growth on Tin and Tin Alloy Surface Finishes

Assembly Cleanliness and Whisker Formation

Final Inspection after 16,000 hours 25°C, 85%RH

Eva Kosiba
Celestica

WP1753

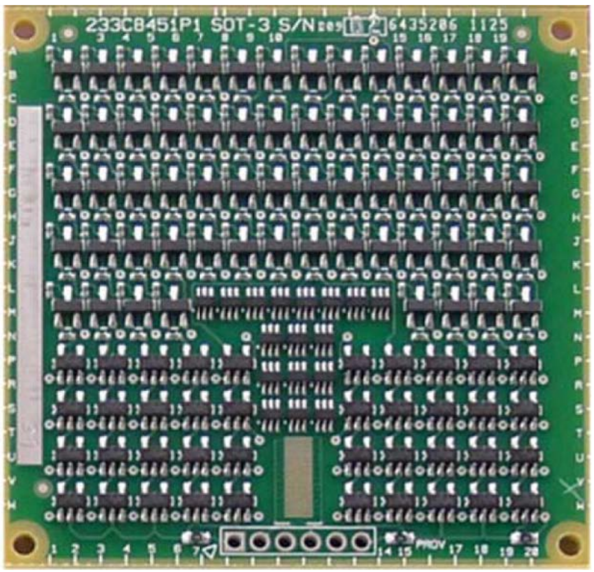
Stephan Meschter[1], Polina Snugovsky[2], Eva Kosiba[2], Zohreh Bagheri[2], Jeffrey Kennedy[2]

[1]BAE Systems, [2]Celestica Inc.,

Outline

- Test Vehicle
- Cleanliness and Contamination
- Exposure
- Results after Exposure
  - Whisker Inspection
  - Cross Sectional Analysis
- Summary of Findings

Test Vehicle

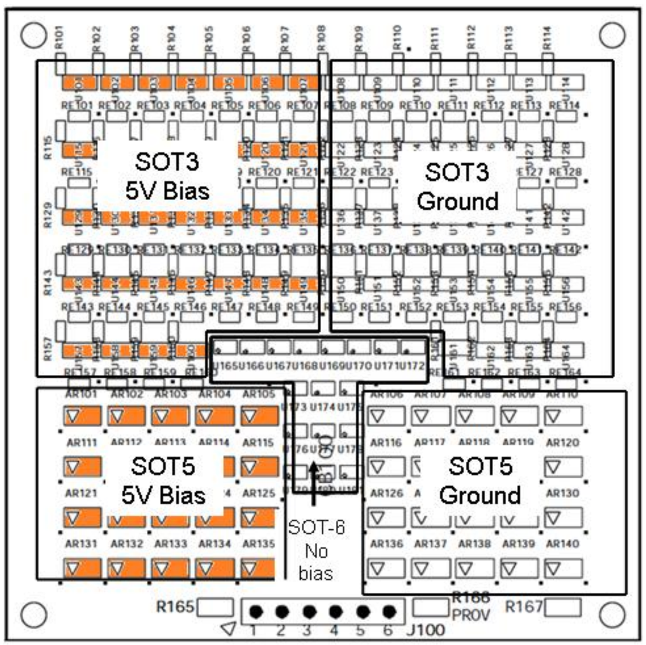


Immersion tin finish printed wire board

Part			Lead Frame	Lead Finish	# Leads /Board
	2N7002 (SOT23-3)	SOT3	Alloy 42	Matte Sn	192
	NC7S08M5X (SOT23-5)	SOT5	Cu194	Matte Sn	200
	2N7002DW 7-F (SOT363)	SOT6	Alloy 42	Matte Sn	102

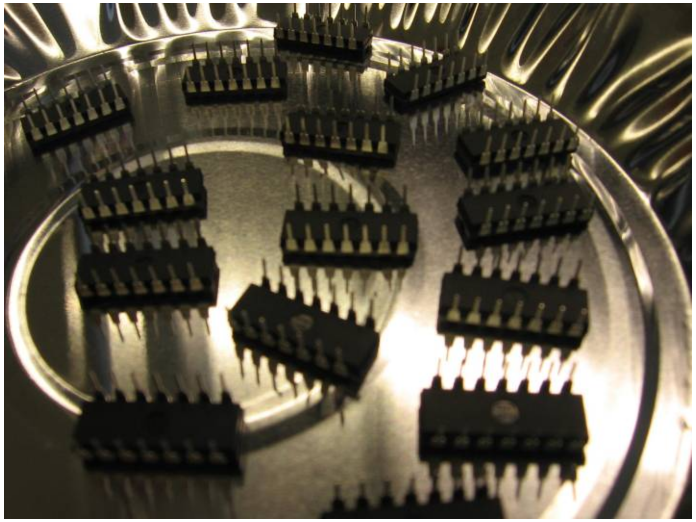
Lead Frame Material	Composition
Alloy 42	Fe-42Ni
Cu194	Cu2.1-2.6Fe-0.015-0.15P-0.05-0.2Zn

Test Vehicle – bias testing



Component	Applied Power	Lead	Bias 1	Bias 2
SOT3	ground	All	0	0
	5V	1	5	5
		2	5	0
		3	5	5
SOT5	ground	All	0	0
	5V	1	5	0
		2	5	5
		3	5	0
		4	5	0
		5	5	5
SOT6	No Connect	All	0	0

Component Cleaning

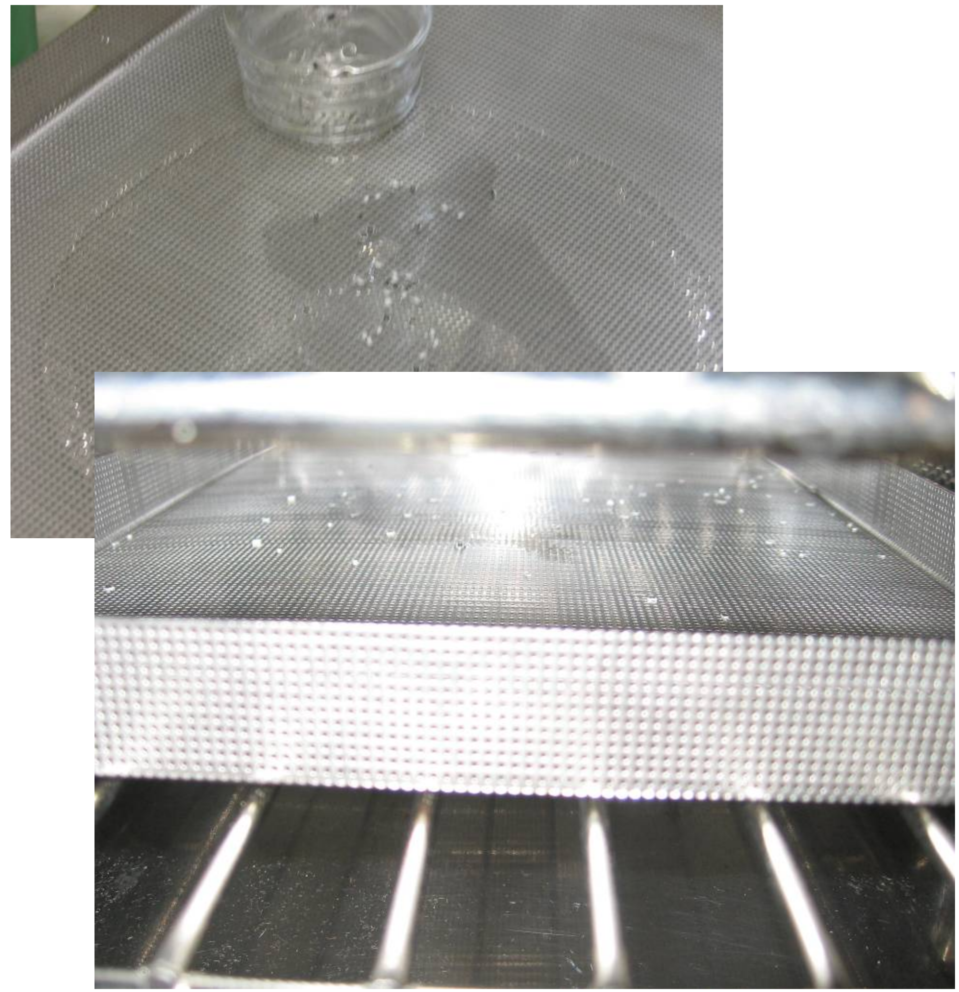


Component Cleanliness Levels

Component	Total Inorganic Anions (µg/in^2)	Total Organic Anions (µg/in^2)
SOT3	0.4	3.3
SOT5	0.3	0.0
SOT6	0.2	3.5

Component	Total Inorganic Anions (µg/in^2)					
	Fluoride	Chloride	Nitrite	Bromide	Nitrate	Sulphate
SOT3	0.0	0.0	0.0	0.0	0.2	0.2
SOT5	0.1	0.0	0.0	0.0	0.1	0.0
SOT6	0.1	0.0	0.0	0.0	0.1	0.0

Component Contamination



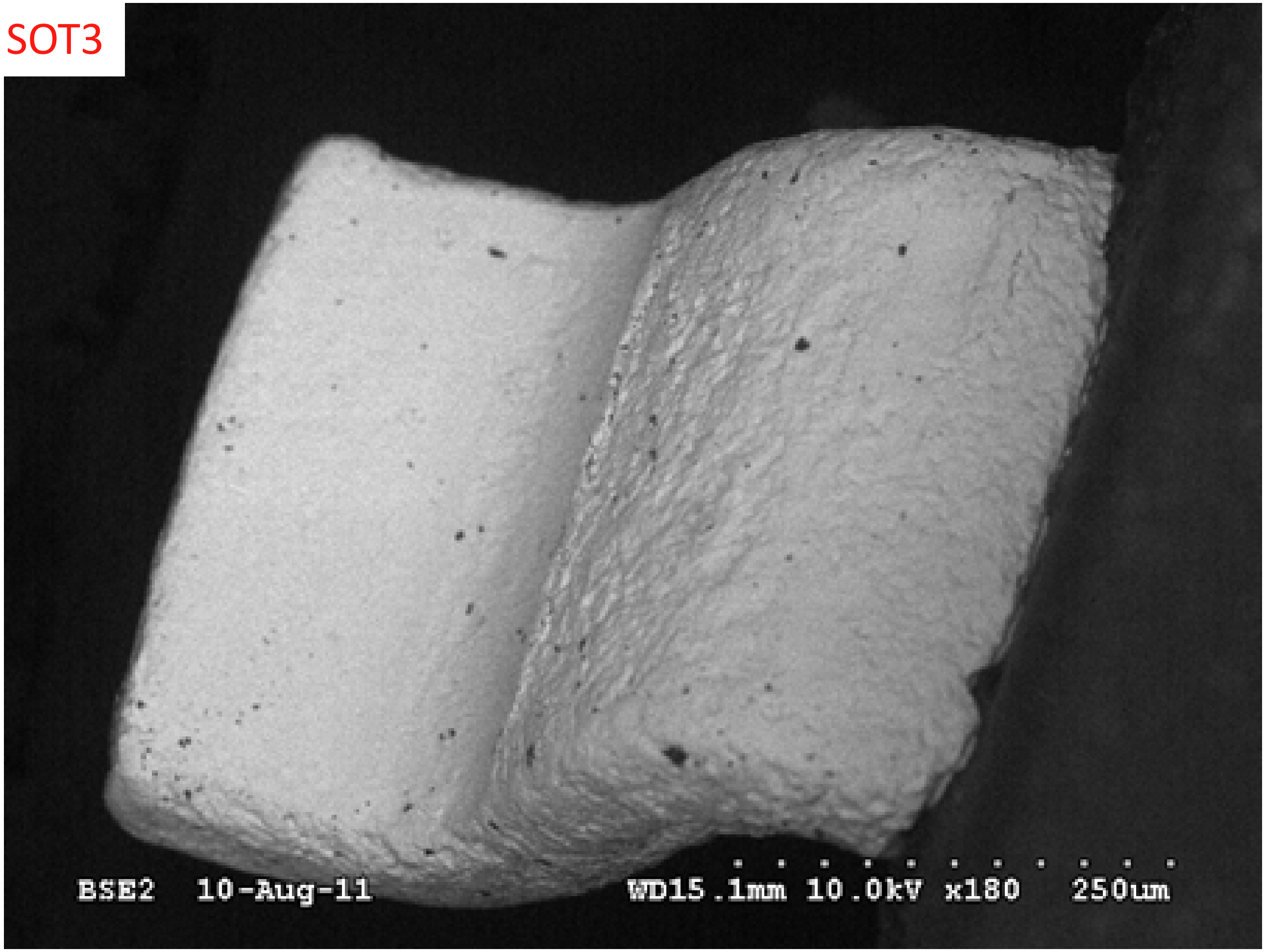
Component Contamination Levels

Component	Total Inorganic Anions (µg/in^2)	Total Organic Anions (µg/in^2)
SOT3	1.9 – 2.3	0.0
SOT5	8.7	0.0
SOT6	7.4	0.0

Component	Total Inorganic Anions (µg/in^2)					
	Fluoride	Chloride	Nitrite	Bromide	Nitrate	Sulphate
SOT3	0.1	1.7 – 2.2	0.0	0.0	0.0 - 0.1	0.1
SOT5	0.3	6.7	0.0	0.0	0.0	0.7
SOT6	0.1	7.2	0.0	0.0	0.1	0.1

Component Contamination

SOT3

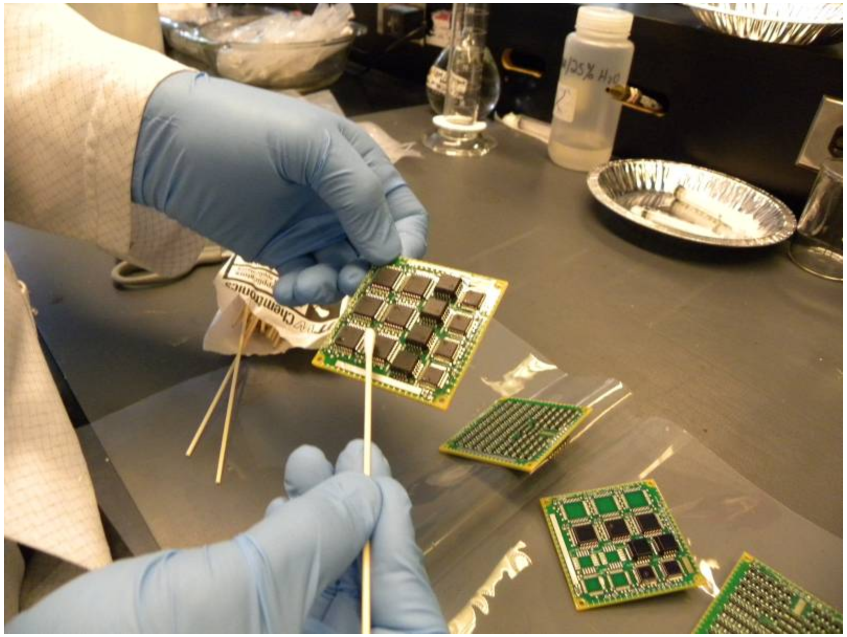


Test Vehicle Panel

Post Assembly Cleaning

Post Assembly Contamination

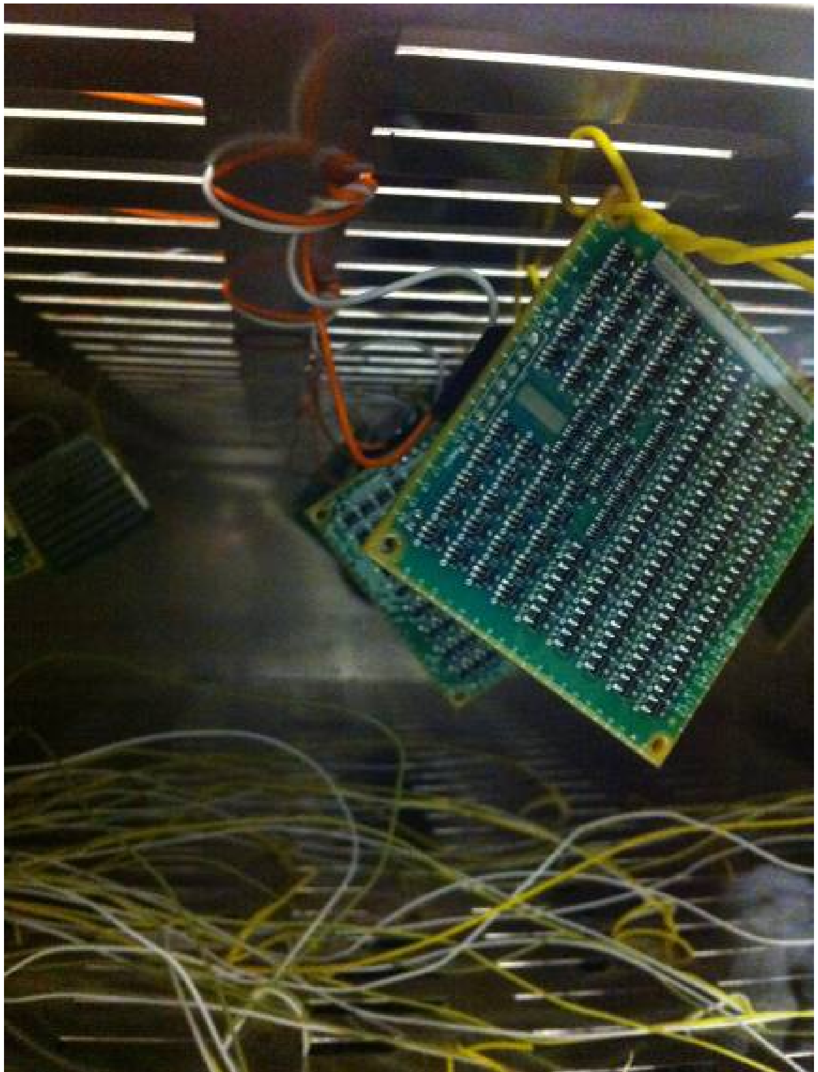
- Boards submerged in solution
  - (160ppm chloride salt)
- Agitated for 30 minutes at room temperature
- Solution beading on component bodies removed prior to bake



Contamination Conditions

Component Condition		Assembly Condition		Labelling Convention
Condition	Level (µg/in^2)	Condition	Level (µg/in^2)	
Clean	<0.4	Clean	N/A	0-0
Contaminated	2-8	Clean	N/A	1-0
Clean	<0.4	Contaminated	>10	0-1
Contaminated	2-8	Contaminated	>10	1-1

Exposure: 25°C / 85% RH 16,000 hours



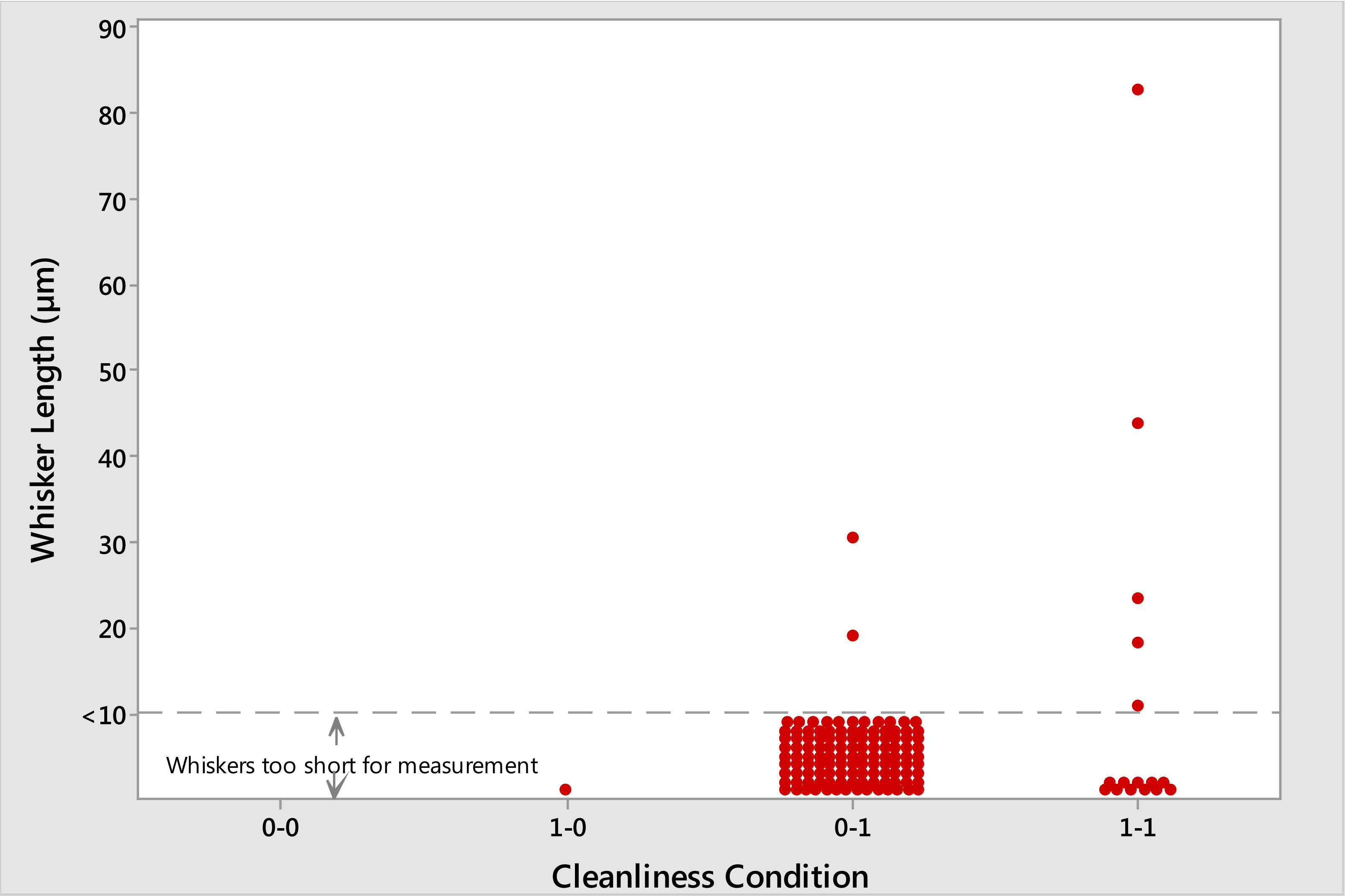
Whisker Inspection

Component	Counted	Measured
SOT3	134	8
SOT5	4,428	457
SOT6	160	11
Total	***4,754***	***476***

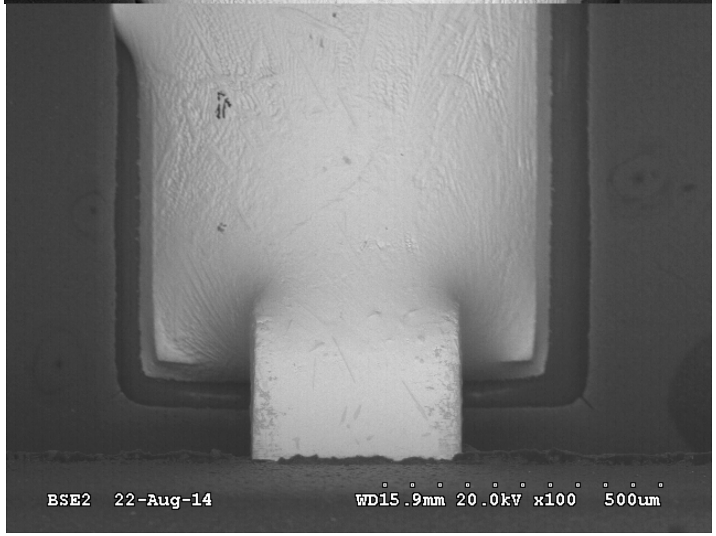
SOT3 –16,000 hours 25°C/85%RH

Cleanliness	Components	% Components w Whiskers	Leads	% Leads w Whiskers	Total Whiskers	Measured Whiskers	Longest Whisker
	Components w Whiskers		Leads w Whiskers				
0-0	48	0	144	0	0	0	0
	0		0				
1-0	48	2.1	144	0.01	1	0	0
	1		1				
0-1	48	25	144	12.5	117	2	30.6
	12		18				
1-1	48	14.6	144	6.9	16	5	82.9
	7		10				

SOT3 –16,000 hours 25°C/85%RH



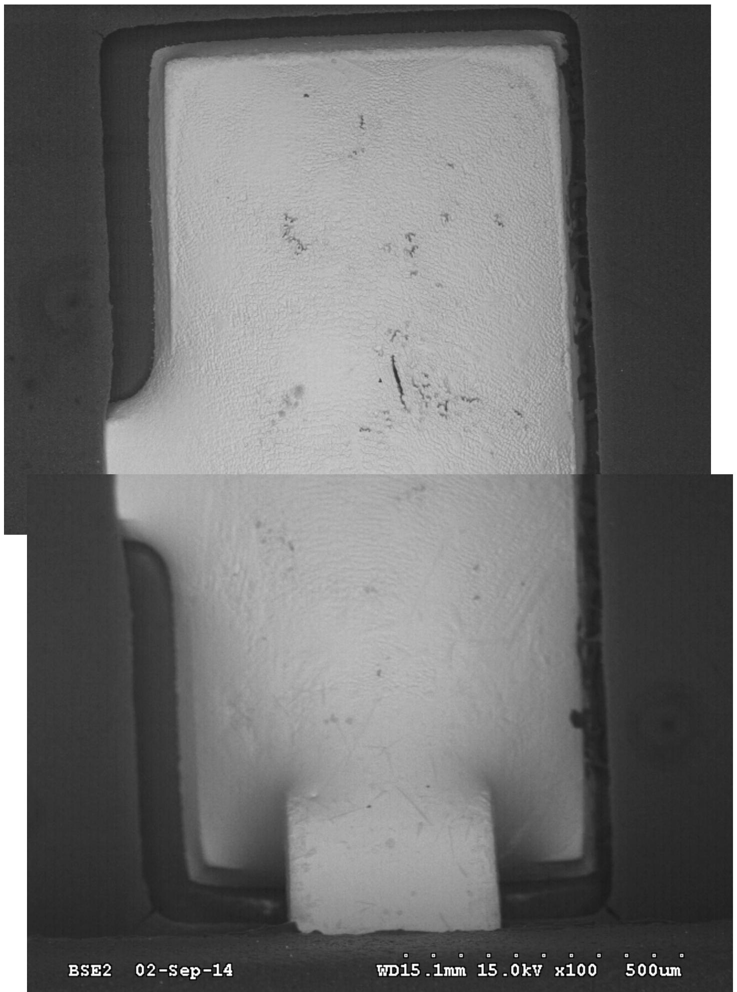
SOT3 0-0



- No Oxide
- No Whiskers

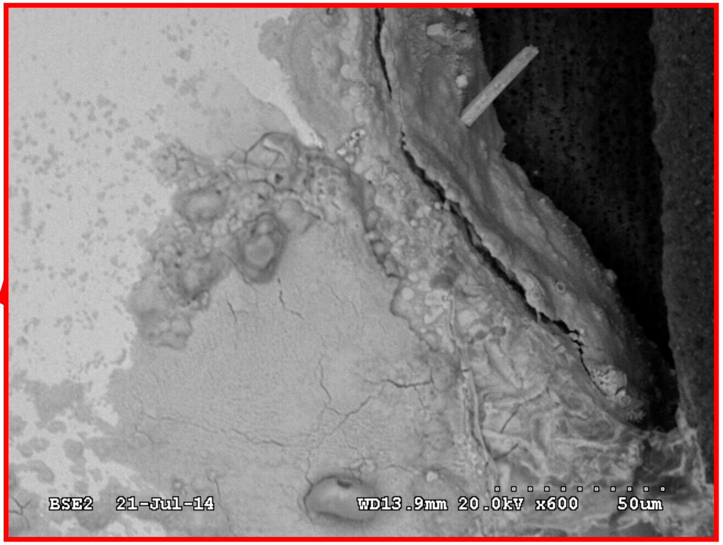
SOT3 1-0

- Small Amount of Oxide
- 1 Short Whisker



SOT3 0-1

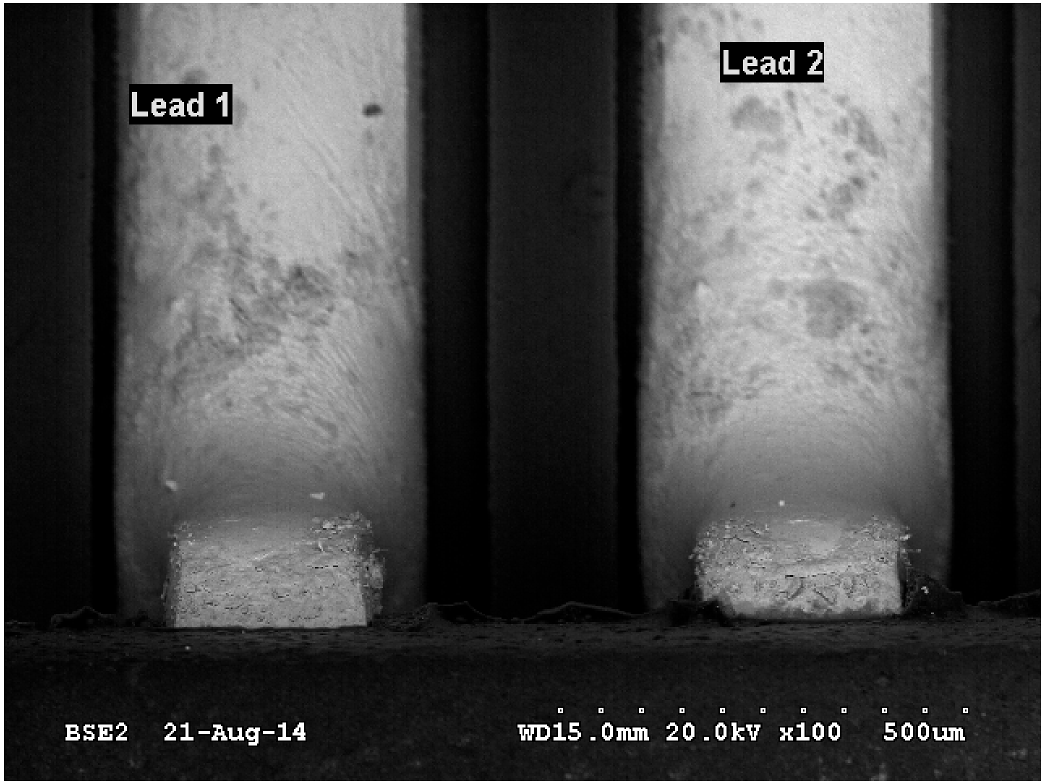
- Significant Oxide Formation
- Many Short Whiskers
- Whiskers formed near site of Oxidation



SOT3 1-1

- Significant Oxide Formation
- Short Whiskers

SOT3 1-1


Lead 1
Lead 2
BSE2 21-Aug-14
WD15.0mm 20.0kV x100 500um


BSE2 21-Aug-14
WD15.1mm 20.0kV x1.5k 20um


BSE2 21-Aug-14
WD15.0mm 20.0kV x3.0k 10um

SOT3 1-1

- Oxide forms around IMC

- Both Normal and Hollow Whiskers Form

SOT5 –16,000 hours 25°C/85%RH

<table>
<tr><th rowspan="2">Cleanliness</th><th>Components</th><th rowspan="2">% Components w Whiskers</th><th>Leads</th><th rowspan="2">% Leads w Whiskers</th><th rowspan="2">Total Whiskers</th><th rowspan="2">Measured Whiskers</th><th rowspan="2">Longest Whisker</th></tr>
<tr><th>Components w Whiskers</th><th>Leads w Whiskers</th></tr>
<tr><td rowspan="2">0-0</td><td>16</td><td rowspan="2">6.2</td><td>80</td><td rowspan="2">1.2</td><td rowspan="2">6</td><td rowspan="2">0</td><td rowspan="2">0</td></tr>
<tr><td>1</td><td>1</td></tr>
<tr><td rowspan="2">1-0</td><td>16</td><td rowspan="2">31.2</td><td>80</td><td rowspan="2">6.2</td><td rowspan="2">27</td><td rowspan="2">0</td><td rowspan="2">0</td></tr>
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<tr><td rowspan="2">0-1</td><td>16</td><td rowspan="2">100</td><td>80</td><td rowspan="2">91.2</td><td rowspan="2">2040</td><td rowspan="2">203</td><td rowspan="2">92.1</td></tr>
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<tr><td rowspan="2">1-1</td><td>16</td><td rowspan="2">100</td><td>80</td><td rowspan="2">98.8</td><td rowspan="2">2355</td><td rowspan="2">254</td><td rowspan="2">80.7</td></tr>
<tr><td>16</td><td>79</td></tr>
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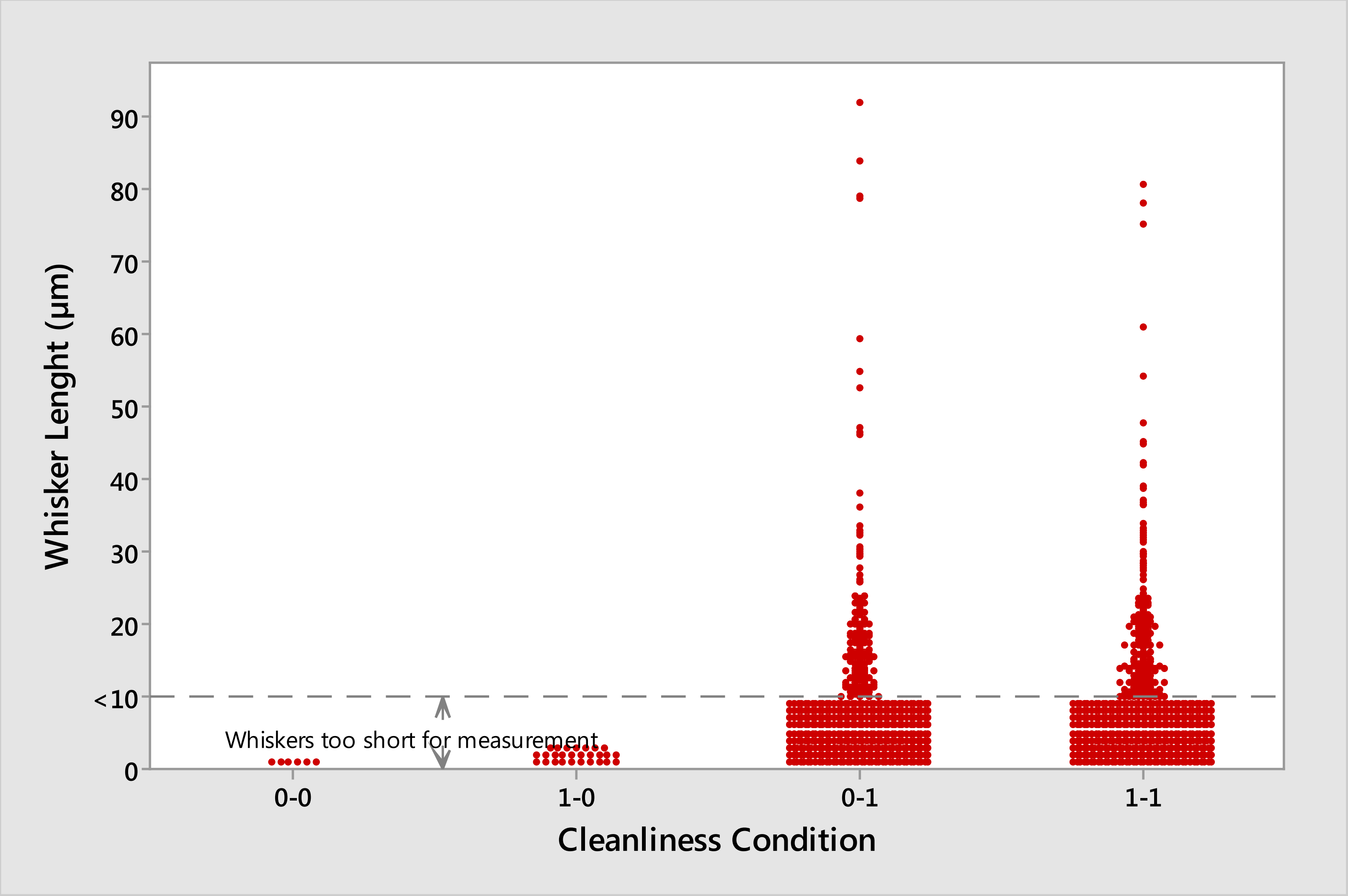
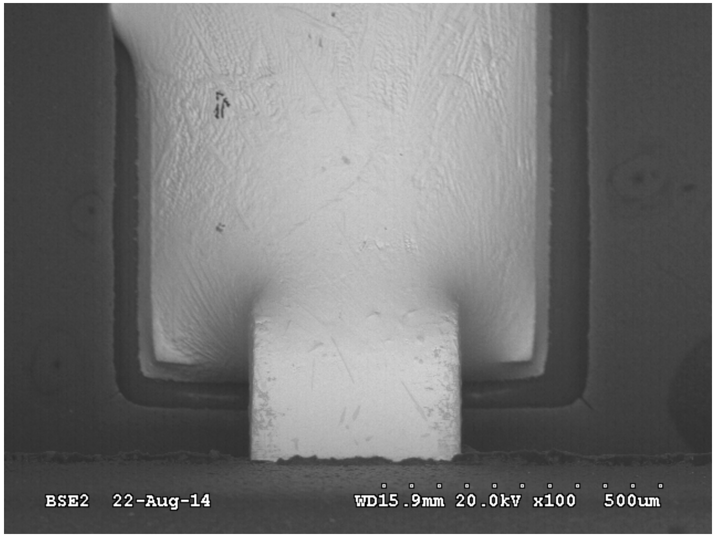
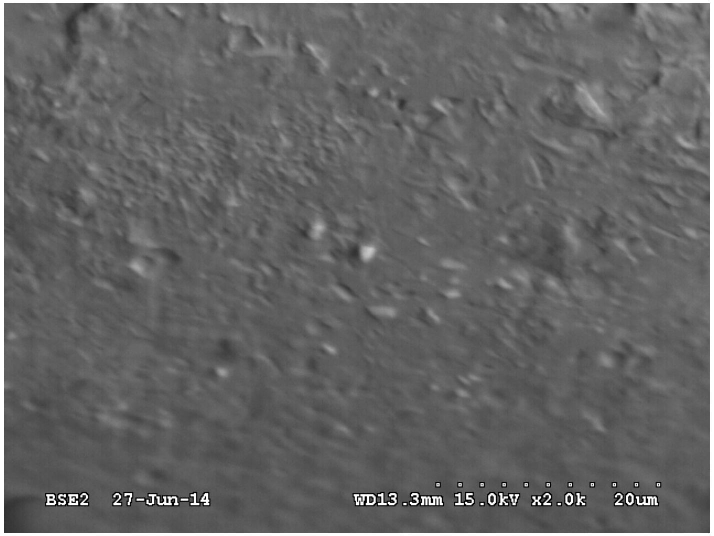
SOT5 –16,000 hours 25°C/85%RH



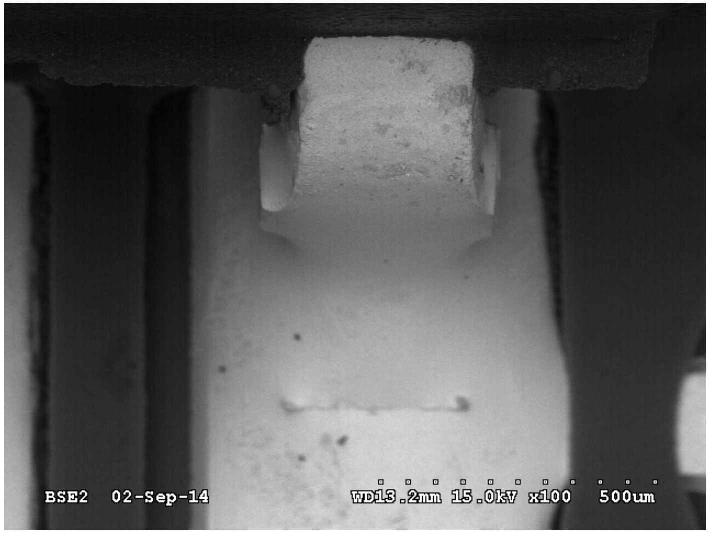
SOT5 0-0





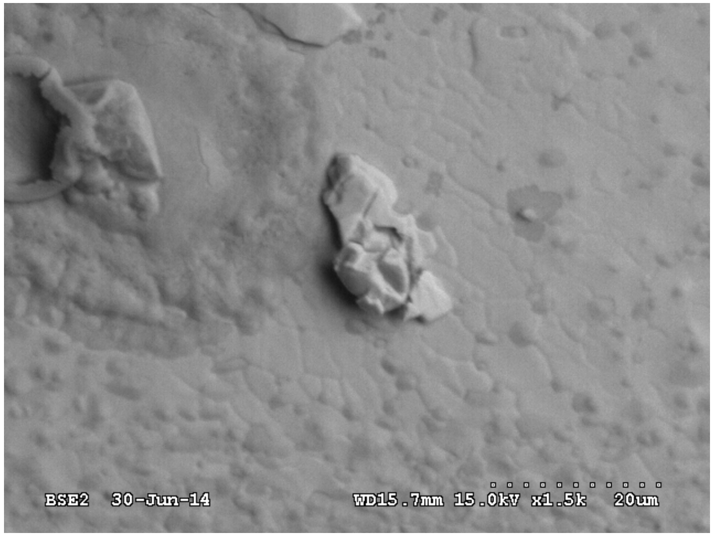
- Almost No Oxide
- Minimal Whiskers

SOT5 1-0

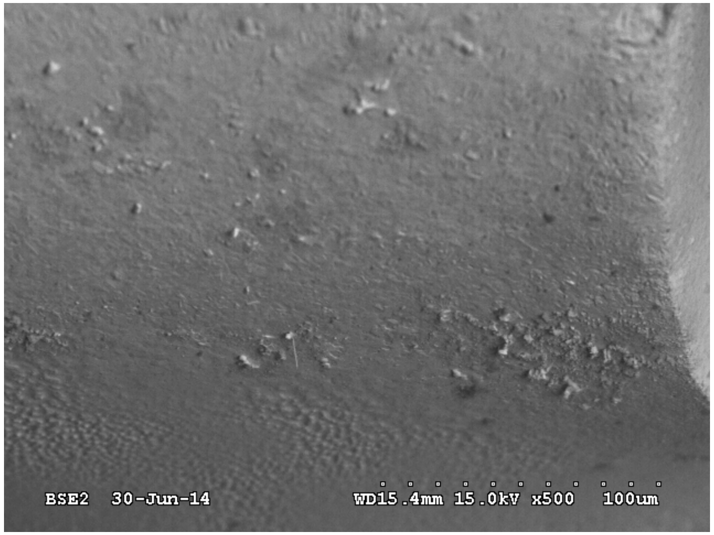


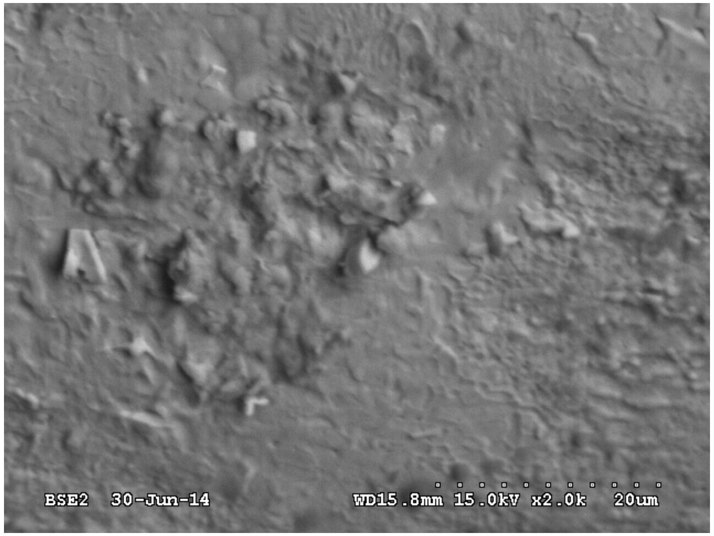
- Almost No Oxide
- Very Short Whiskers

SOT5 1-0

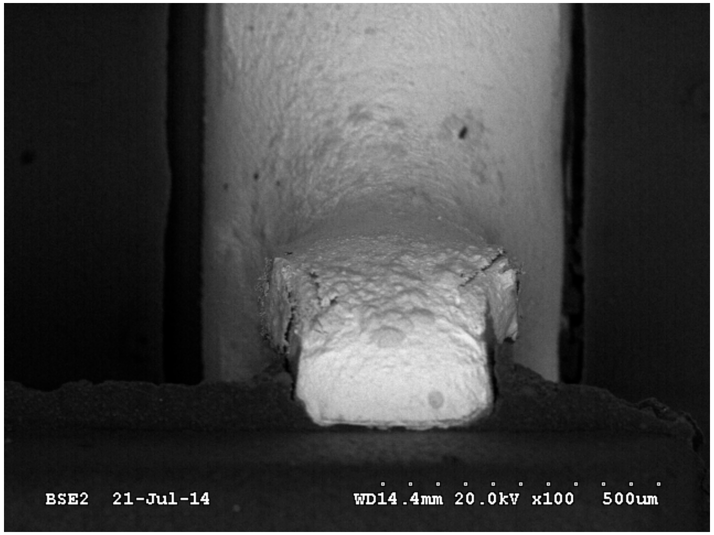


- Recrystallized Grain
- Oxide Around IMC Particles



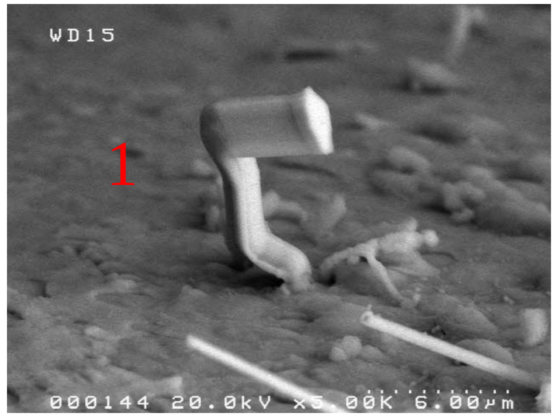


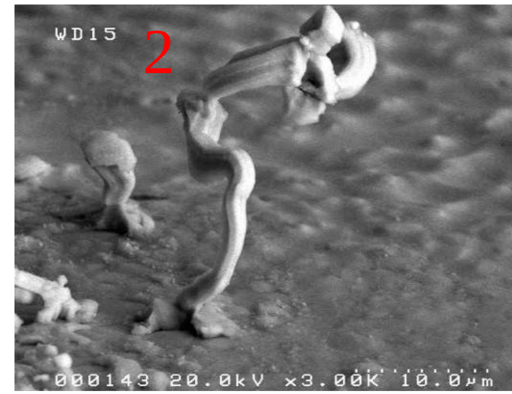
SOT5 0-1



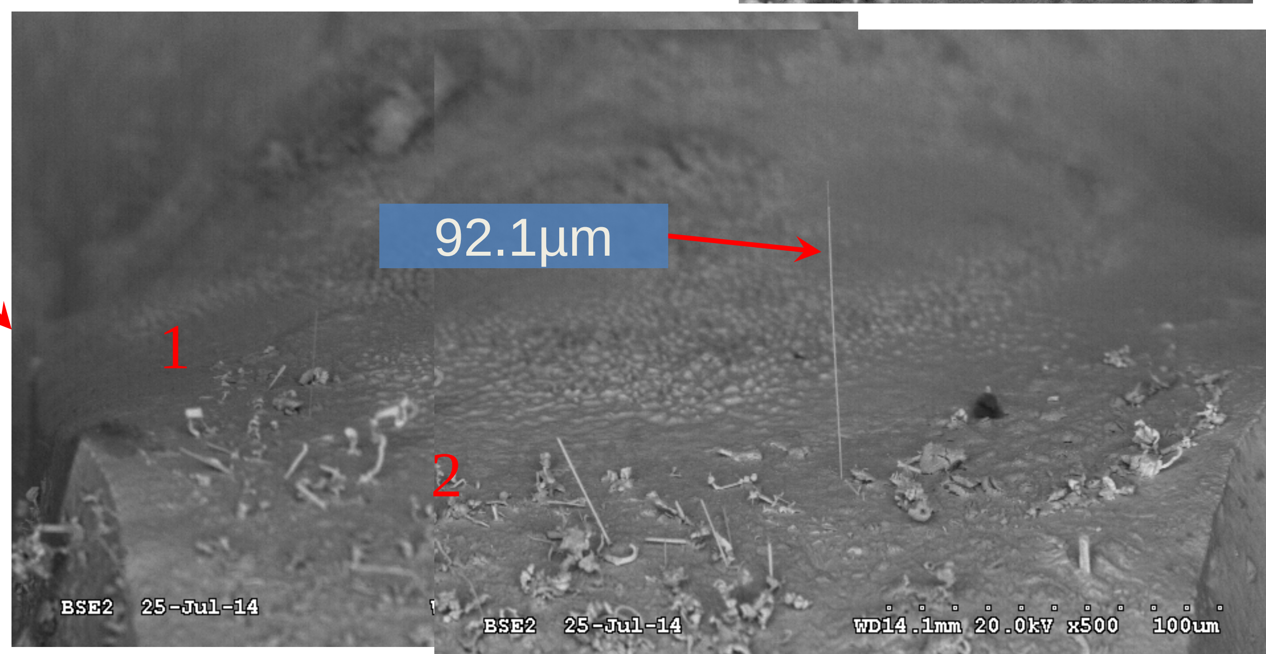
- Lots of Oxidation
- Lots of Whiskers
- Many Short Whiskers
- Long Whiskers
- Hollow Whiskers
- Long, Thin Whiskers with shape similar to Hollow Whiskers

SOT5 0-1

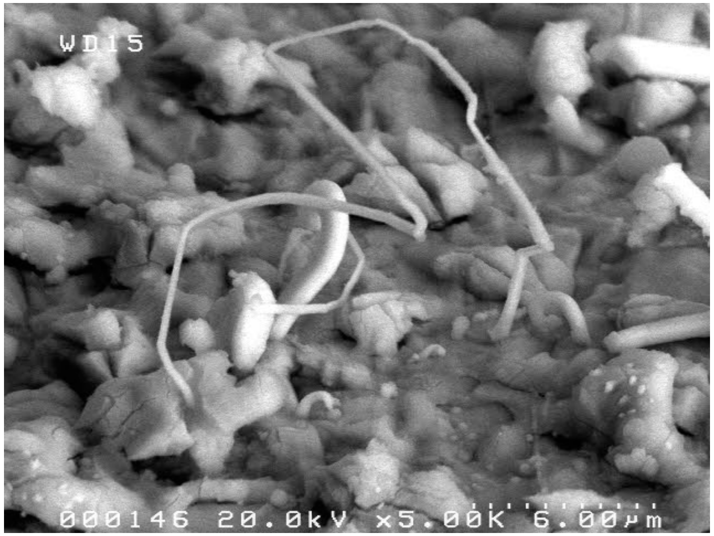

WD15
1
000144 20.0kV x5.00K 6.00µm

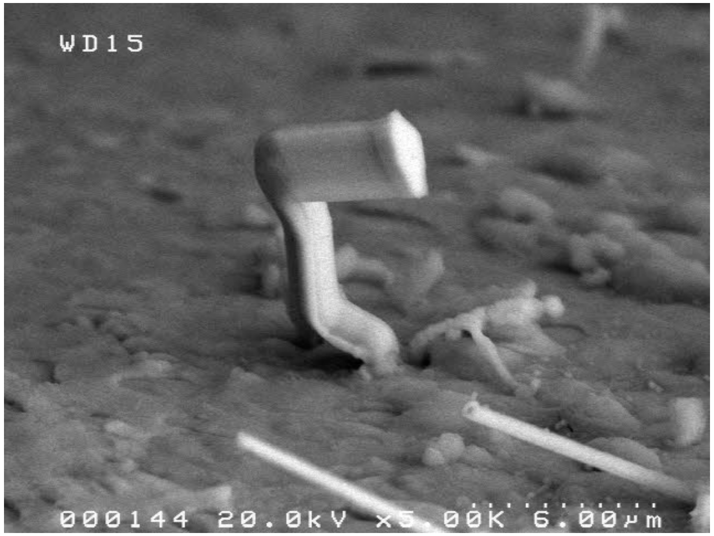

WD15
2
000143 20.0kV x3.00K 10.0µm

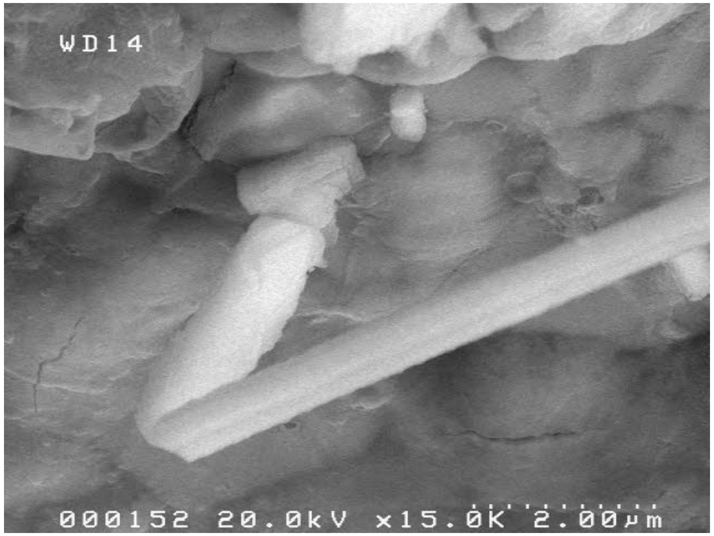

BSE2 25-Jul-14
WD13.8mm 20.0kV x100 500um

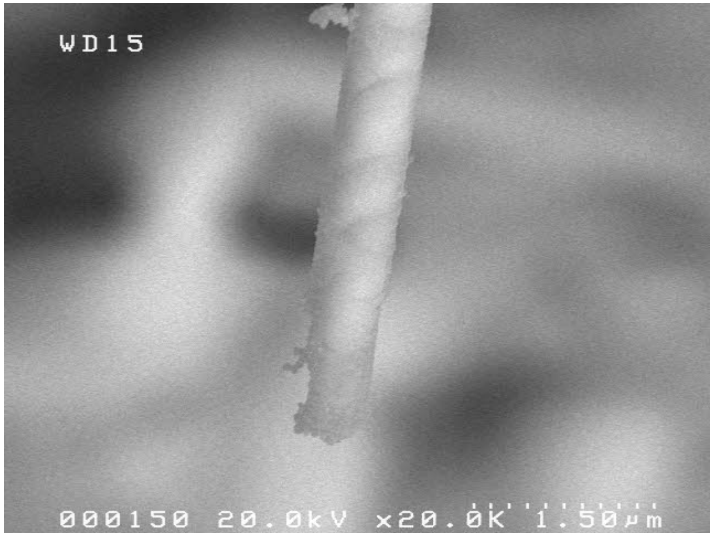

92.1µm
1
2
BSE2 25-Jul-14
BSE2 25-Jul-14
WD14.1mm 20.0kV x500 100um

SOT5 0-1

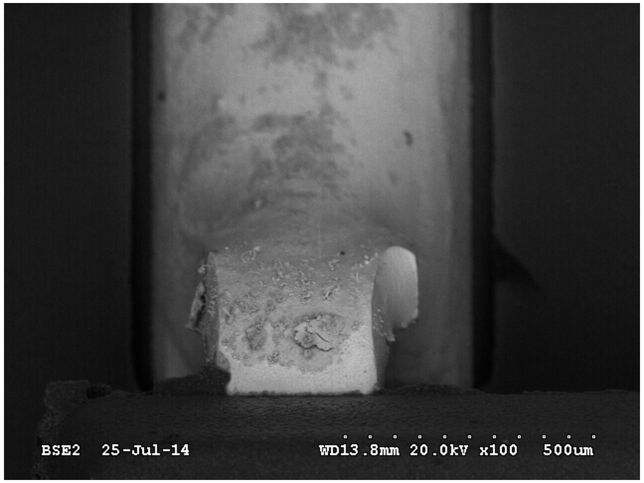

WD15
000146 20.0kV x5.00K 6.00μm


WD15
000144 20.0kV x5.00K 6.00μm


WD14
000152 20.0kV x15.0K 2.00μm


WD15
000150 20.0kV x20.0K 1.50μm

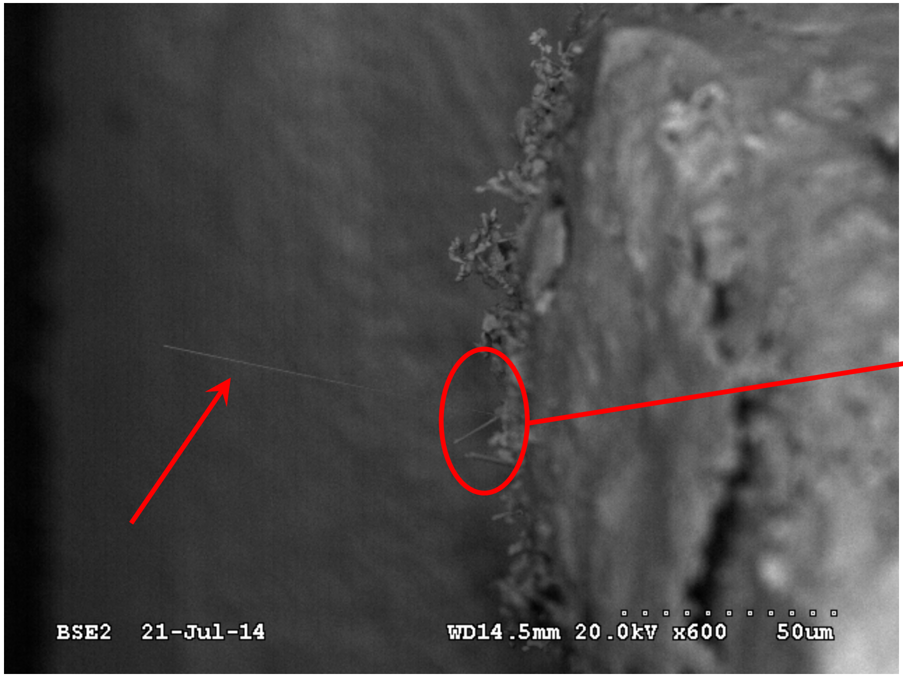
SOT5 0-1

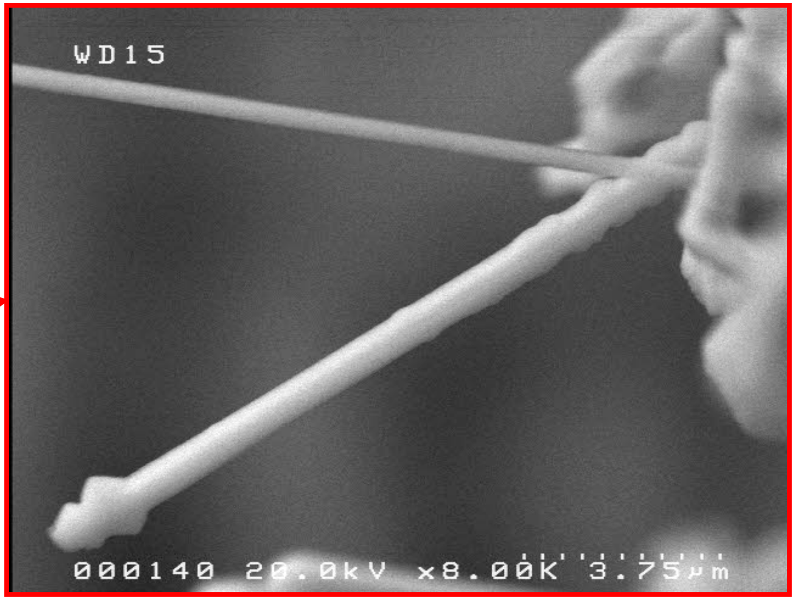

BSE2 25-Jul-14 WD13.8mm 20.0kV x100 500um


BSE2 25-Jul-14 WD14.1mm 20.0kV x1.0k 50um

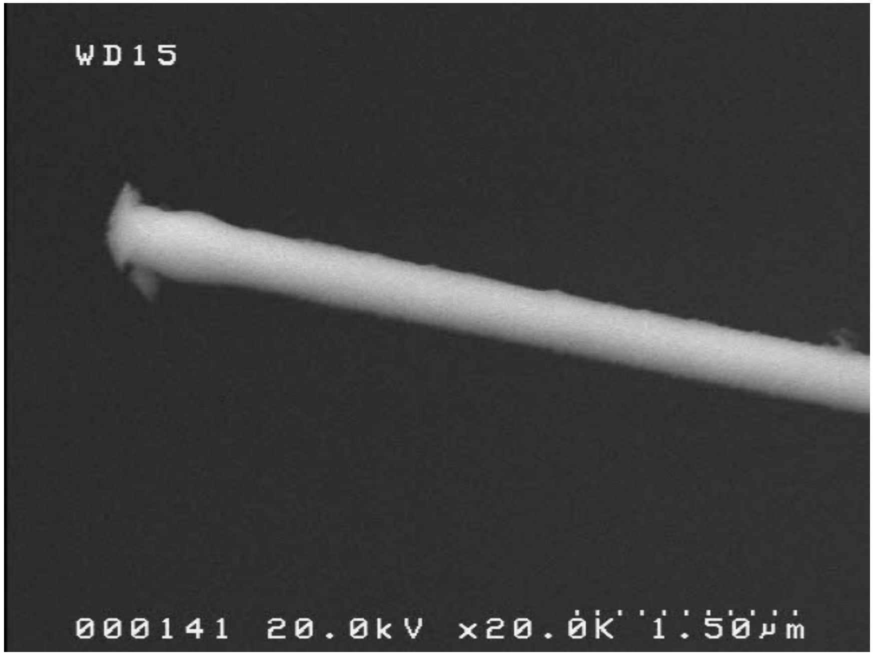

BSE2 25-Jul-14 WD13.9mm 20.0kV x1.8k 25um

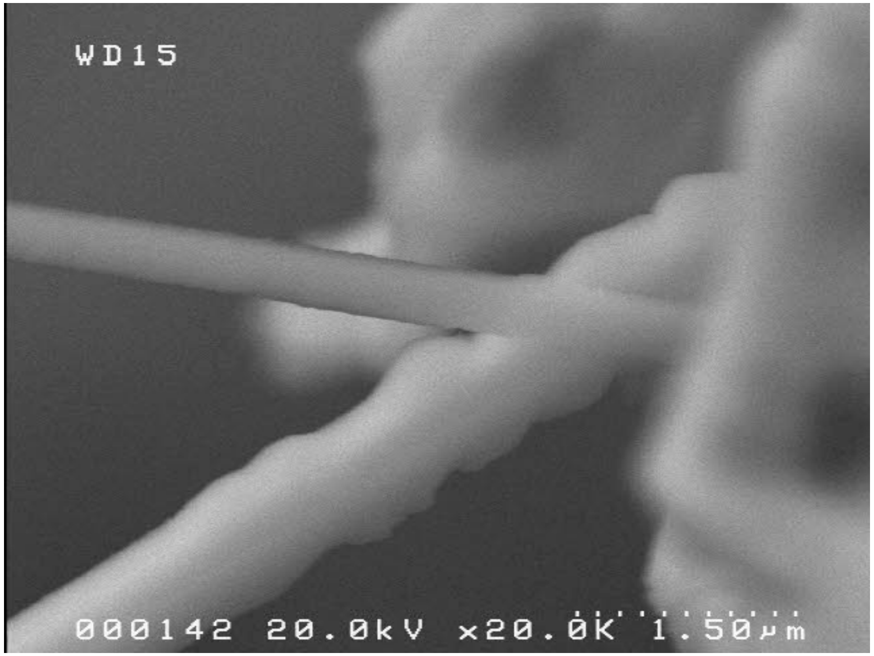
SOT5 0-1



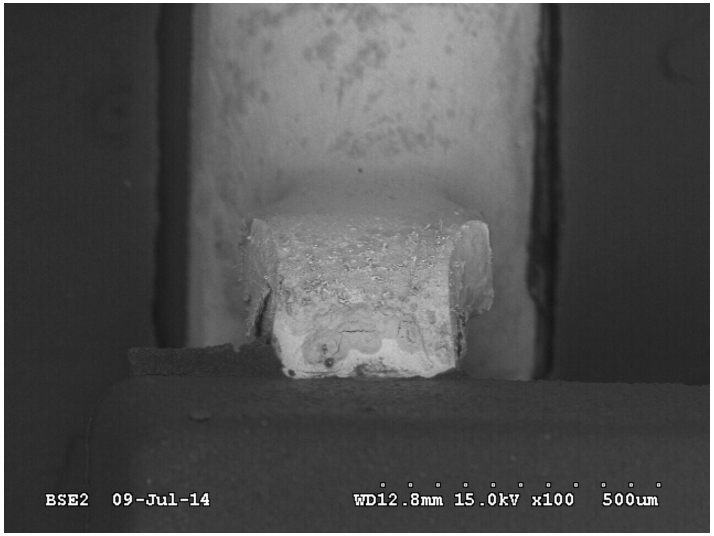


SOT5 0-1


WD15
000141 20.0kV x20.0K 1.50µm


WD15
000142 20.0kV x20.0K 1.50µm

SOT5 0-1

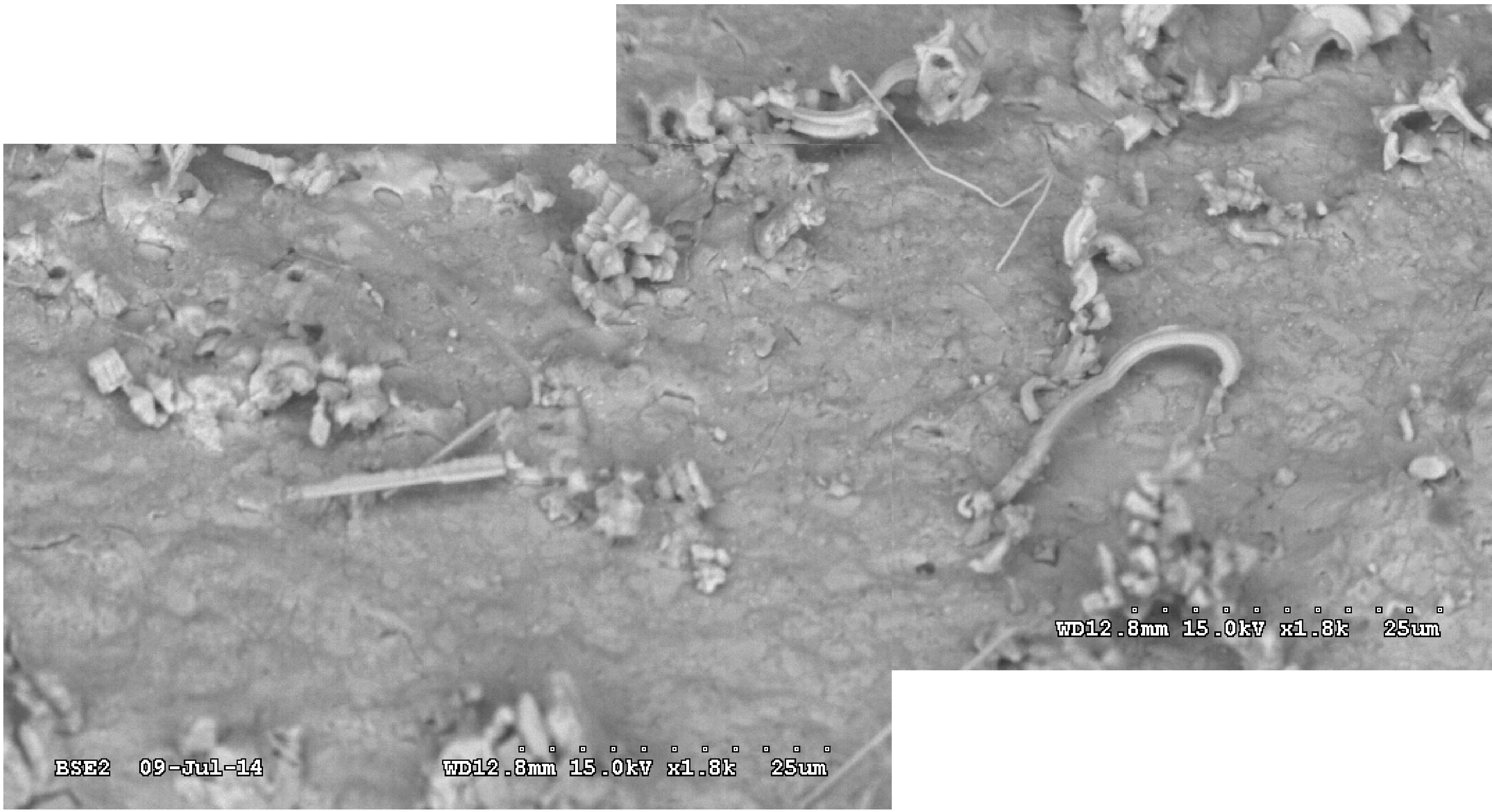

BSE2 09-Jul-14 WD12.8mm 15.0kV x100 500um


BSE2 09-Jul-14 WD12.8mm 15.0kV x1.0k 50um

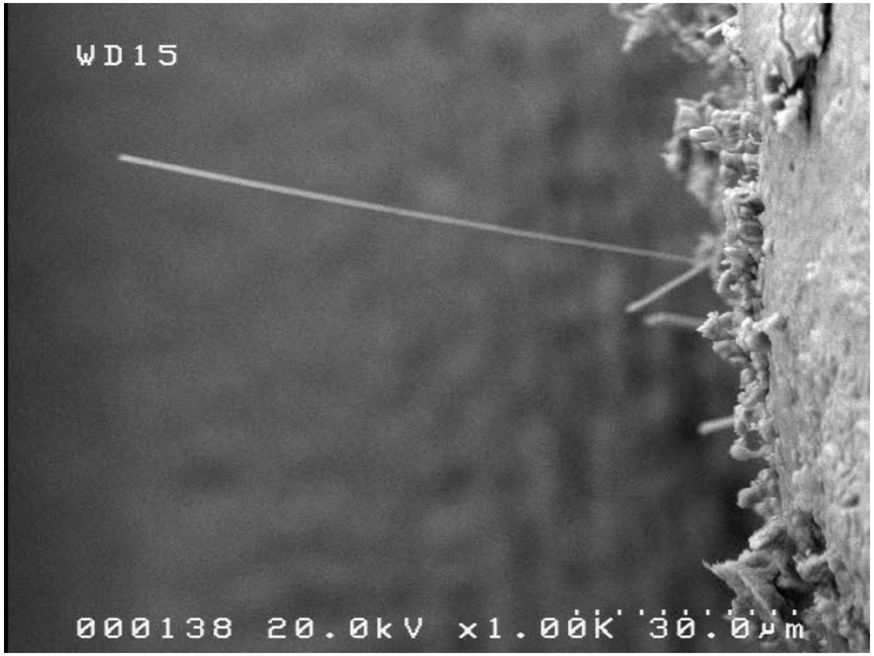

BSE2 09-Jul-14 WD12.9mm 15.0kV x1.8k 25um

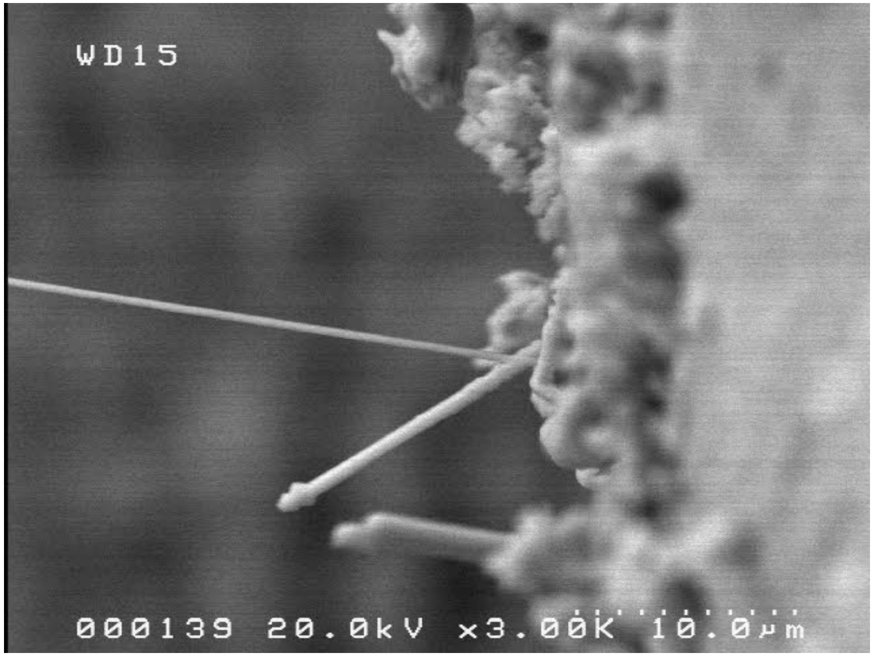

BSE2 09-Jul-14 WD12.8mm 15.0kV x1.5k 20um

SOT5 0-1

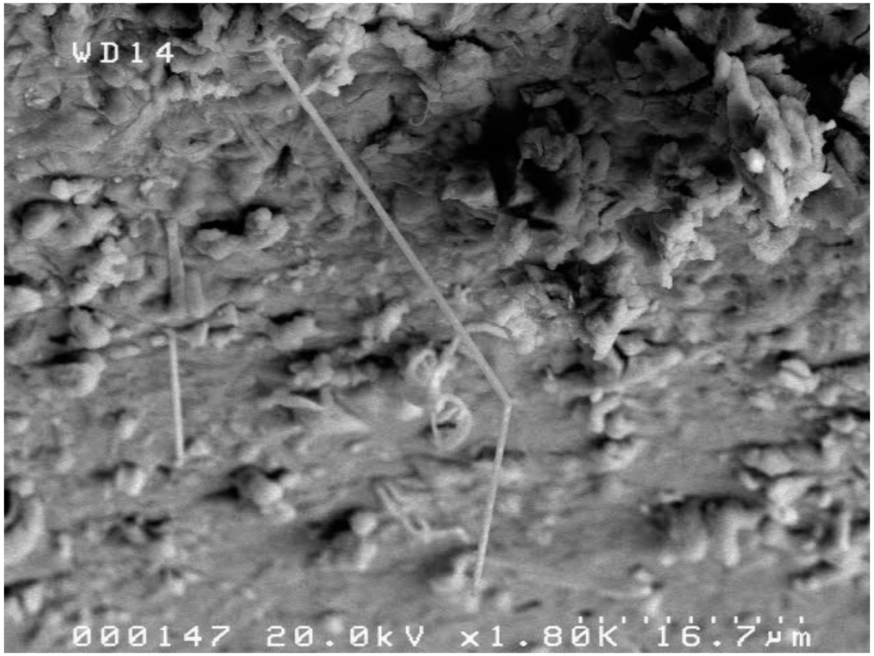

WD12.8mm 15.0kV x1.8k 25um
BSE2 09-Jul-14
WD12.8mm 15.0kV x1.8k 25um

SOT5 0-1


WD15
000138 20.0kV x1.00K 30.0μm


WD15
000139 20.0kV x3.00K 10.0μm

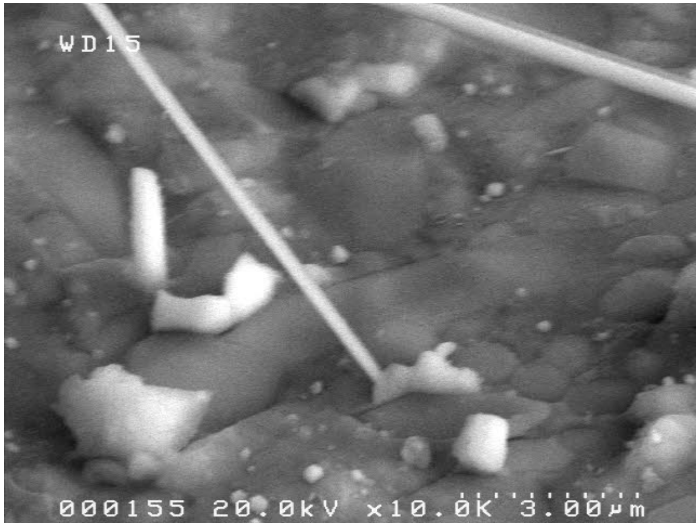
SOT5 0-1


WD14
000147 20.0kV x1.80K 16.7µm


WD14
000151 20.0kV x3.50K 8.57µm

SOT5 1-1

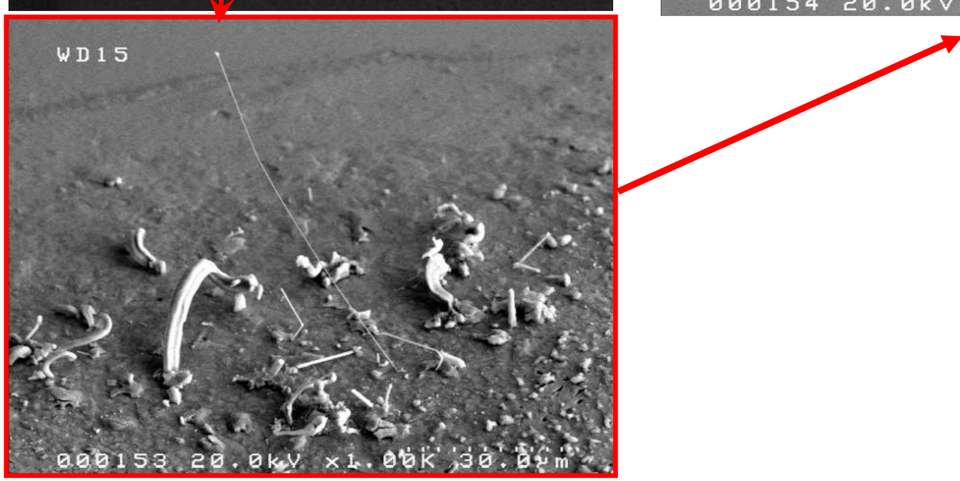
- Lots of Oxidation
- Lots of Whiskers
- Many Short Whiskers
- Long Whiskers
- Hollow Whiskers

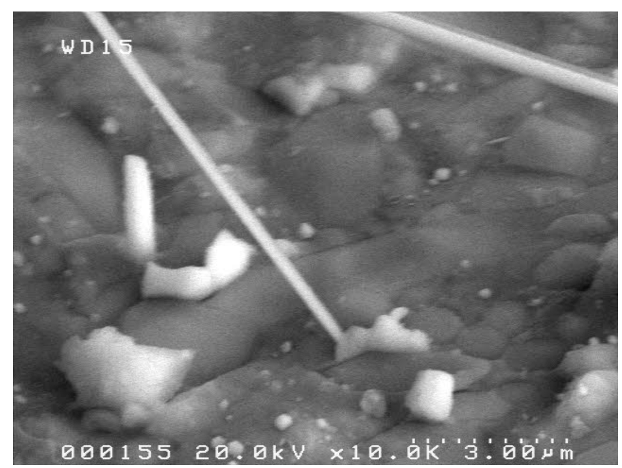


- Long Whiskers are Very Thin

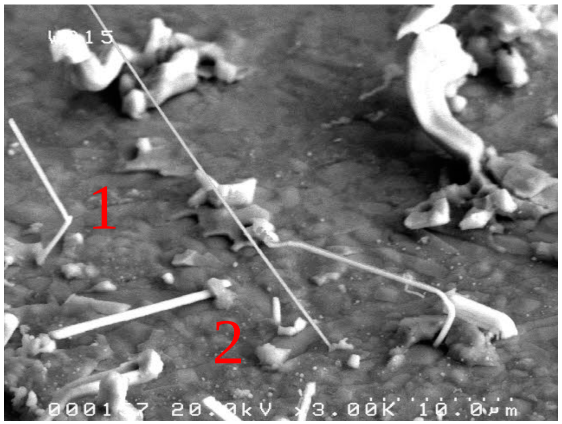
SOT5 1-1

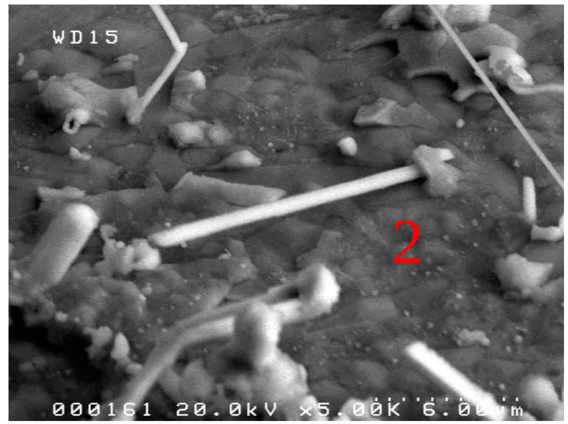
Length – 80.7 µm
Diameter – 0.3µm

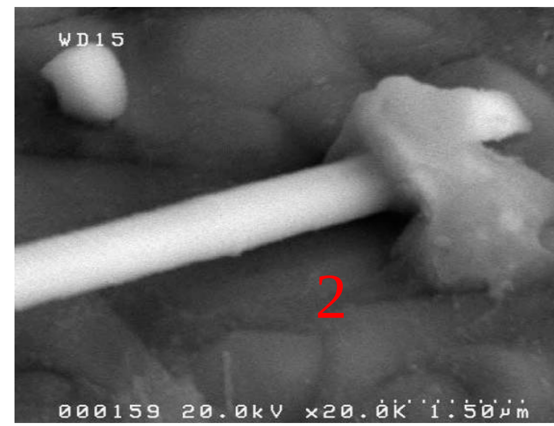


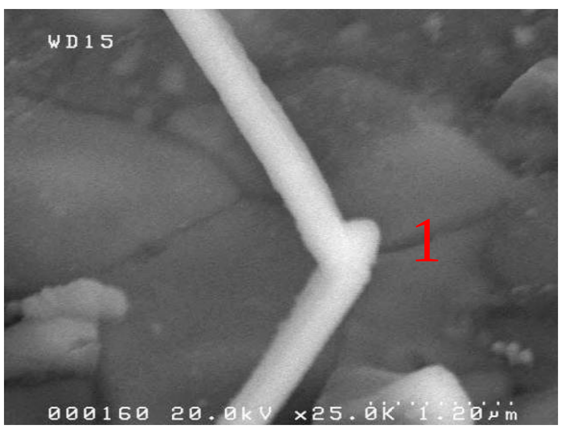


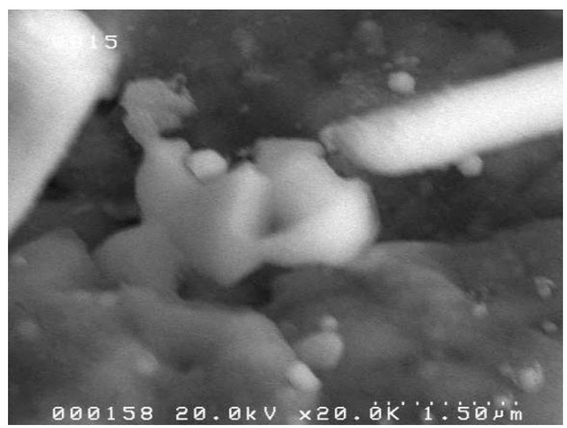
SOT5 1-1


1
2
x3.00K 10.0µm

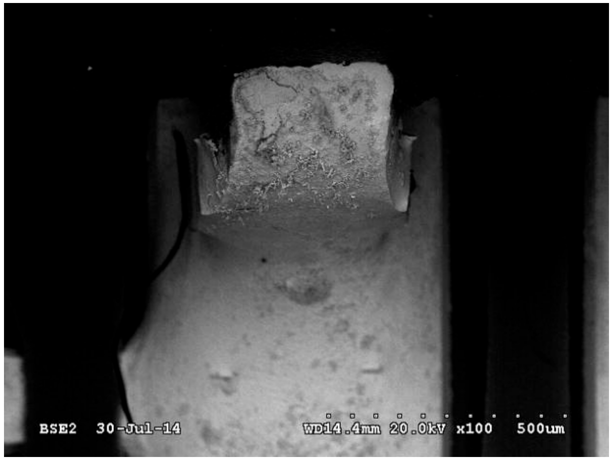

WD15
2
000161 20.0kV


WD15
2
000159 20.0kV x20.0K 1.50µm


WD15
1
000160 20.0kV x25.0K 1.20µm


000158 20.0kV x20.0K 1.50µm

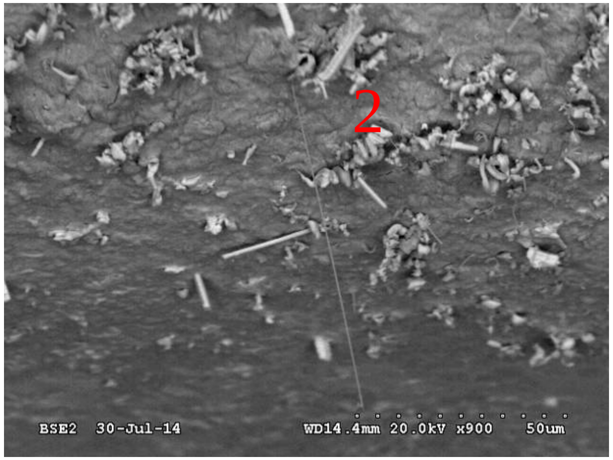
SOT5 1-1


BSE2 30-Jul-14
WD14.4mm 20.0kV x100 500um


1
2
BSE2 30-Jul-14
WD14.3mm 20.0kV x300 100um


1
BSE2 30-Jul-14
WD14.4mm 20.0kV x1.2k 25um

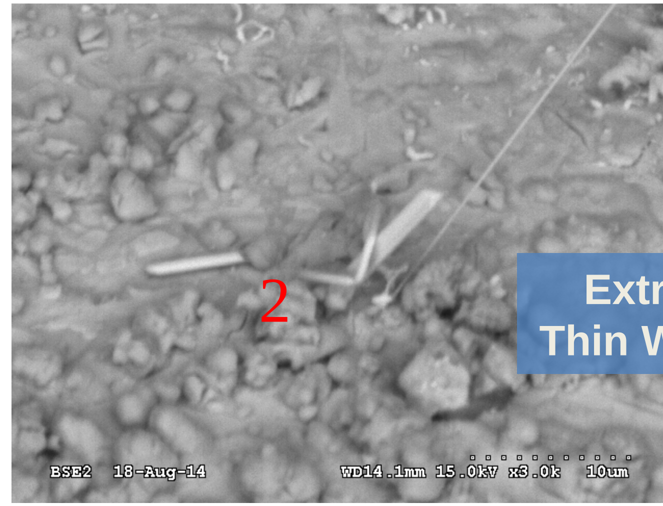

2
BSE2 30-Jul-14
WD14.3mm 20.0kV x1.5k 20um

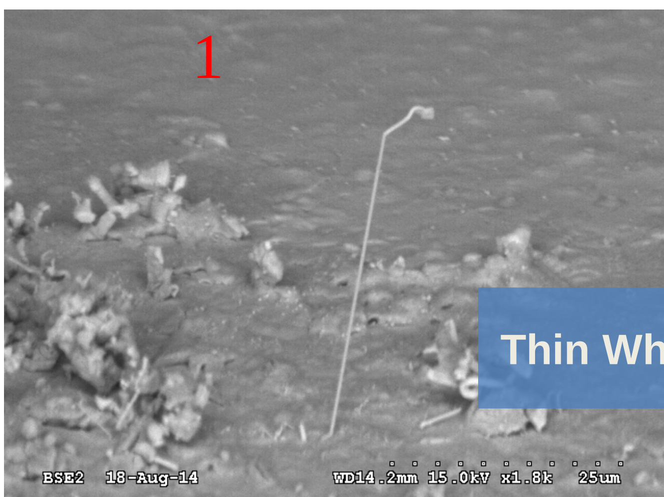

2
BSE2 30-Jul-14
WD14.4mm 20.0kV x900 50um


2

SOT5 1-1

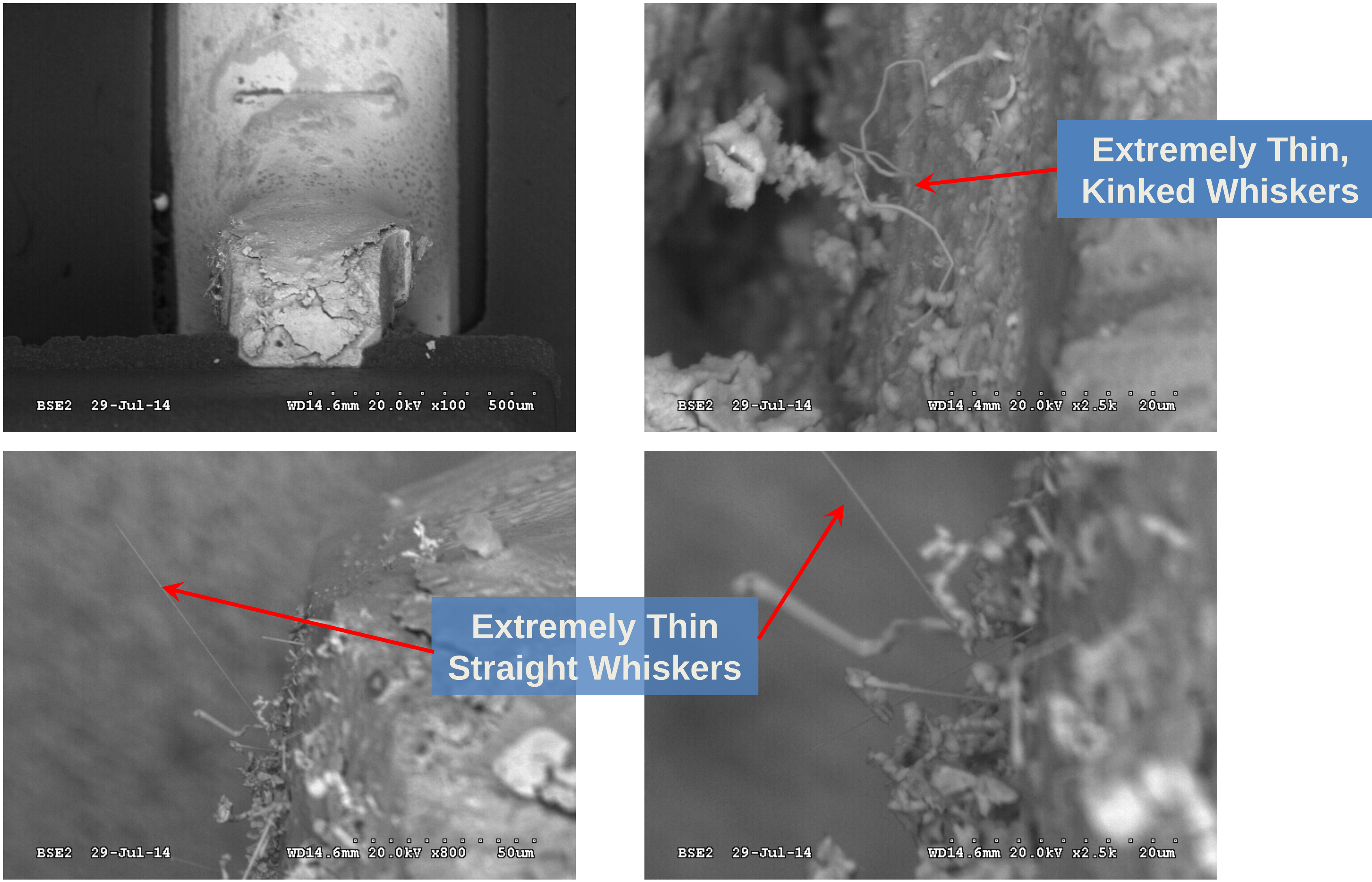

1
2
3
BSE2 18-Aug-14
WD14.1mm 15.0kV x250 200um


2
Extremely Thin Whiskers
BSE2 18-Aug-14
WD14.1mm 15.0kV x3.0k 10um

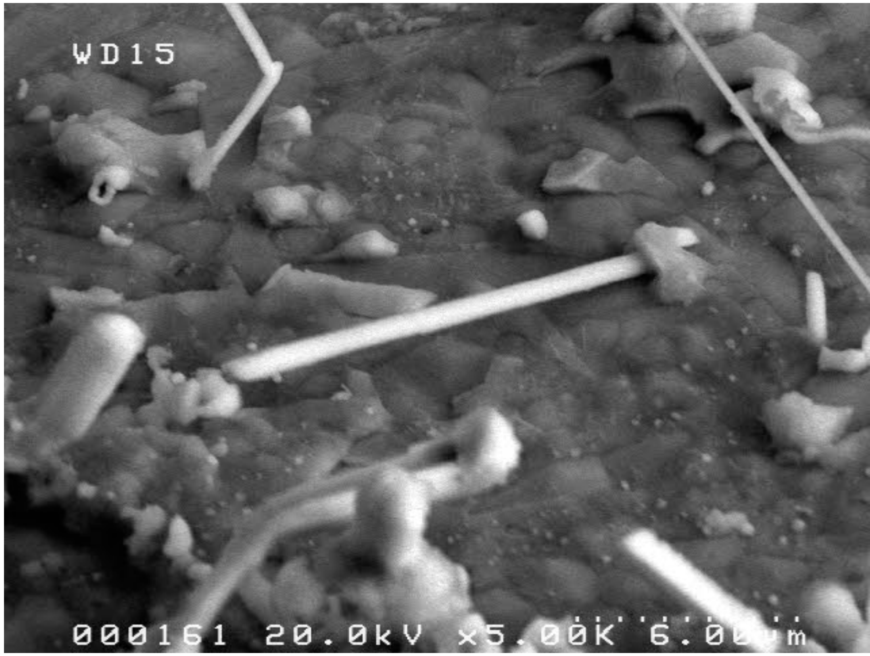

1
Thin Whiskers
BSE2 18-Aug-14
WD14.2mm 15.0kV x1.8k 25um


3
Hollow "Whiskers"
BSE2 18-Aug-14
WD15.1mm 15.0kV x1.5k 20um

SOT5 1-1


BSE2 29-Jul-14 WD14.6mm 20.0kV x100 500um
BSE2 29-Jul-14 WD14.4mm 20.0kV x2.5k 20um
Extremely Thin, Kinked Whiskers
BSE2 29-Jul-14 WD14.6mm 20.0kV x800 50um
Extremely Thin Straight Whiskers
BSE2 29-Jul-14 WD14.6mm 20.0kV x2.5k 20um

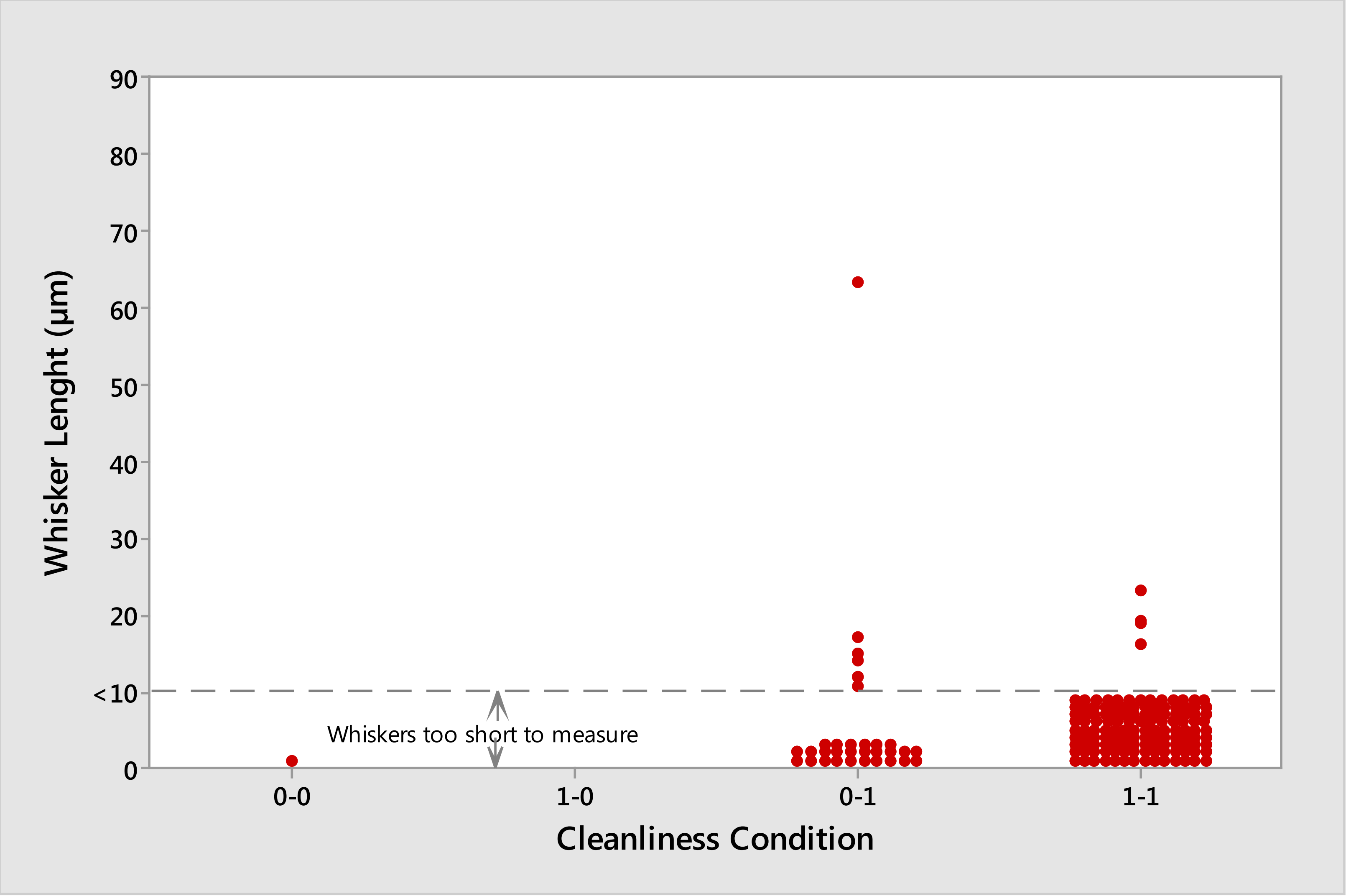
SOT5 1-1



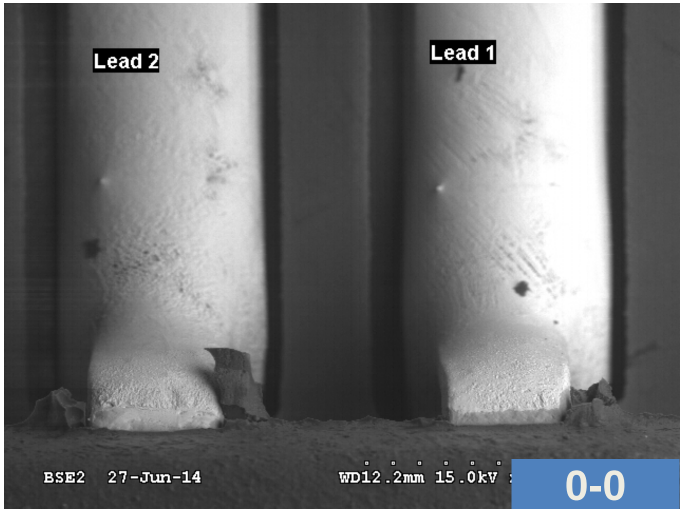
SOT6 –16,000 hours 25°C/85%RH

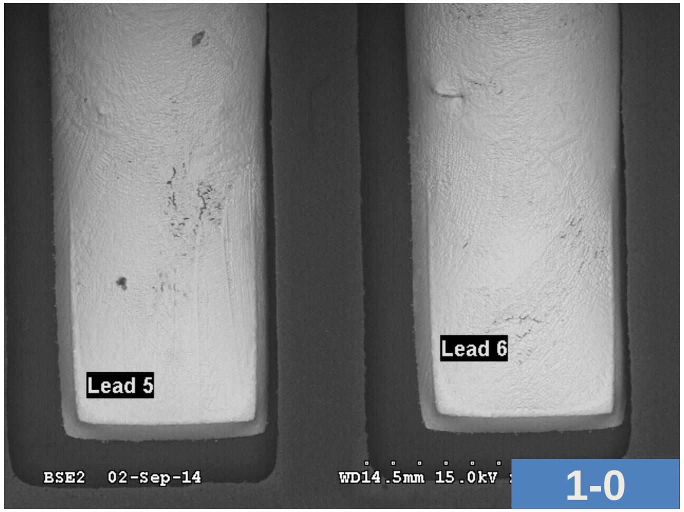
Cleanliness	Components / Components w Whiskers	% Components w Whiskers	Leads / Leads w Whiskers	% Leads w Whiskers	Total Whiskers	Measured Whiskers	Longest Whisker
0-0	8	12.5	48	2.1	1	0	0
	1		1				
1-0	8	0	48	0	0	0	0
	0		0				
0-1	8	100	48	41.7	33	7	63.5
	8		20				
1-1	8	100	48	47.9	126	4	23.2
	8		23				

SOT6 –16,000 hours 25°C/85%RH



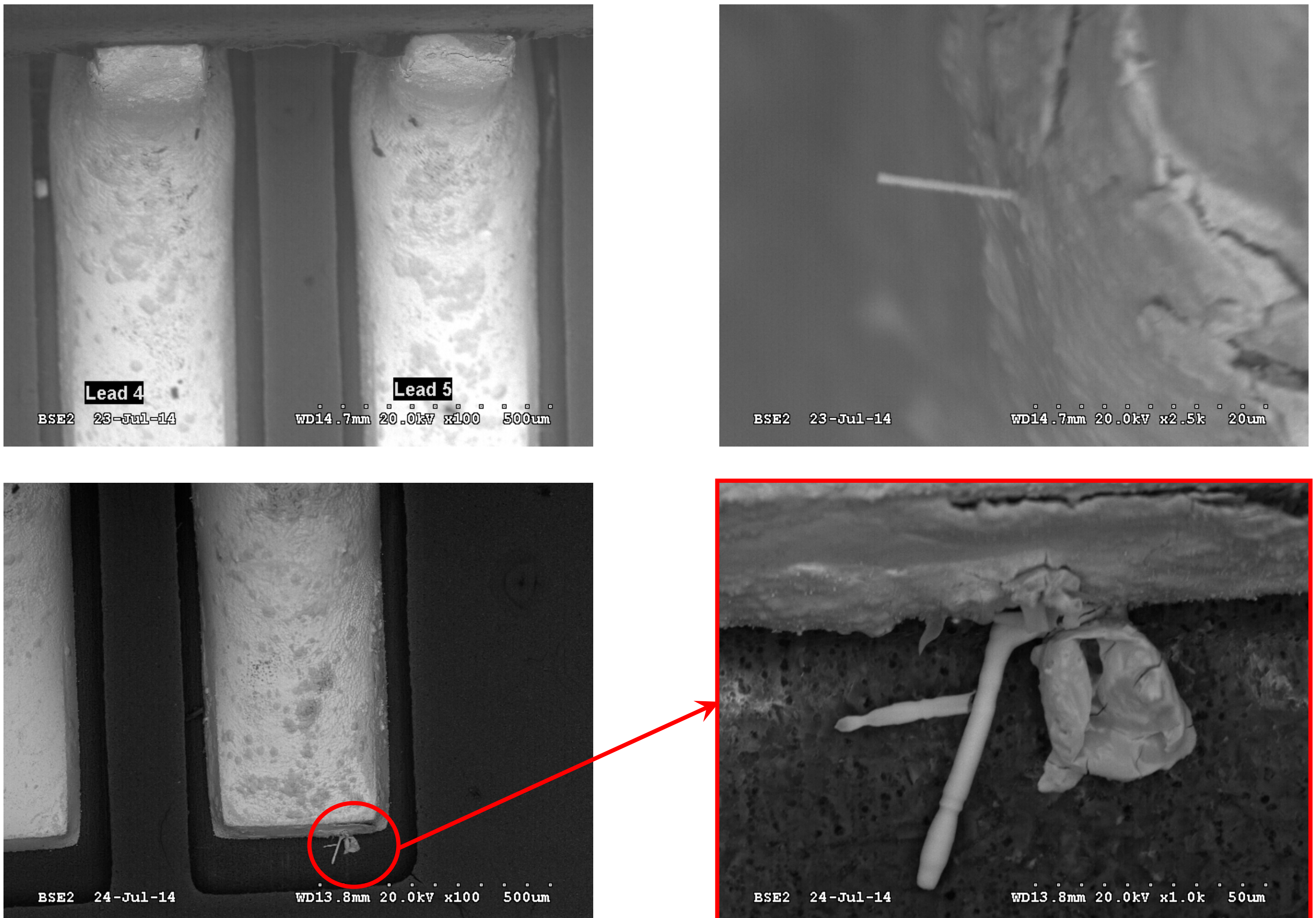
SOT6 0-0, 1-0



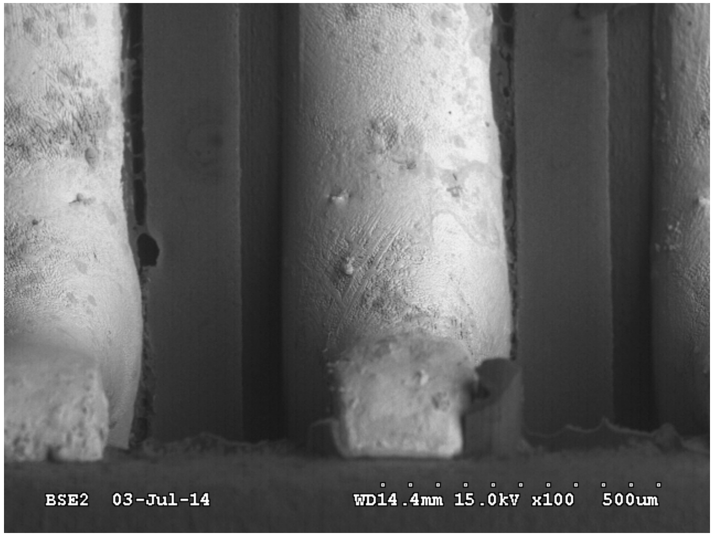


- Little to No Oxide
- No Whisker Formation

SOT6 0-1


Lead 4
Lead 5
BSE2 23-Jul-14
WD14.7mm 20.0kV x100 500um
BSE2 23-Jul-14
WD14.7mm 20.0kV x2.5k 20um
BSE2 24-Jul-14
WD13.8mm 20.0kV x100 500um
BSE2 24-Jul-14
WD13.8mm 20.0kV x1.0k 50um

SOT6 0-1

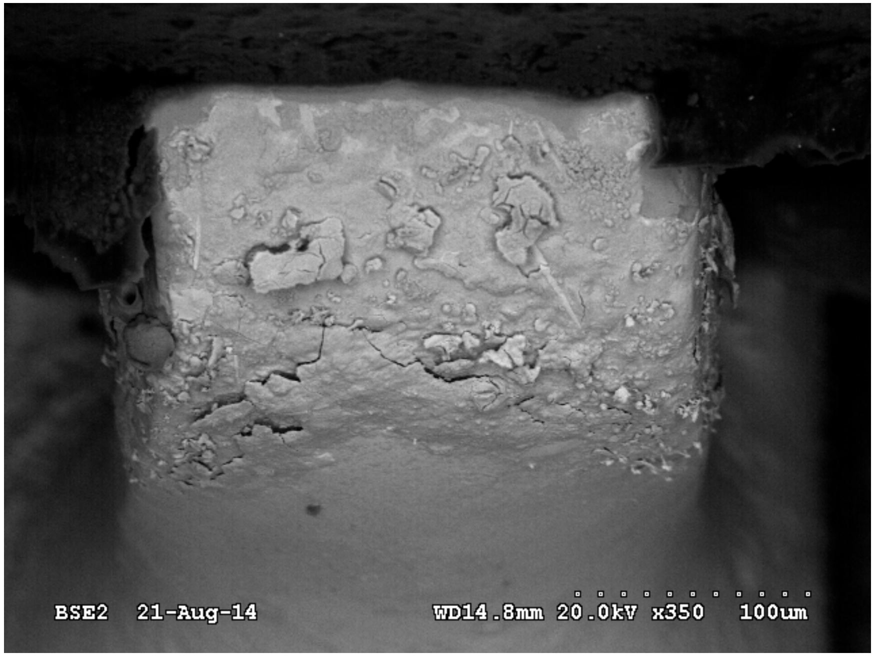

BSE2 03-Jul-14 WD14.4mm 15.0kV x100 500um


BSE2 03-Jul-14 WD13.9mm 15.0kV x1.8k 25um


BSE2 03-Jul-14 WD14.4mm 15.0kV x1.0k 50um

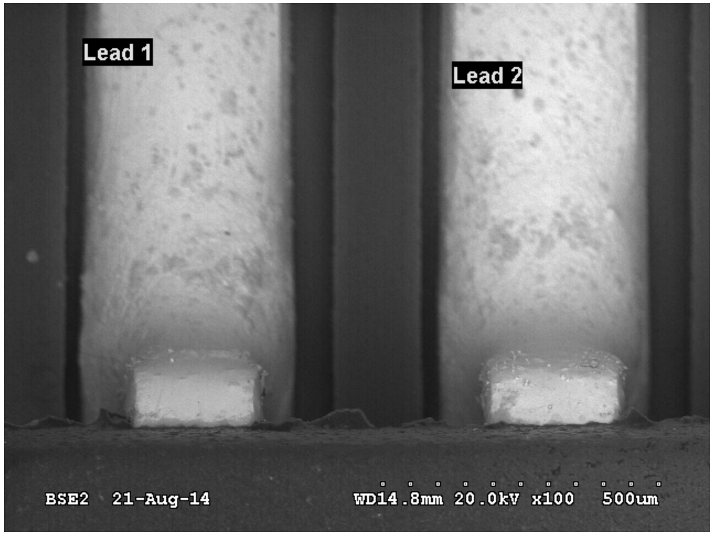

BSE2 03-Jul-14 WD14.5mm 15.0kV x1.0k 50um

SOT6 1-1


BSE2 21-Aug-14
WD14.8mm 20.0kV x350 100um


BSE2 21-Aug-14
WD14.8mm 20.0kV x2.5k 20um

SOT6 1-1

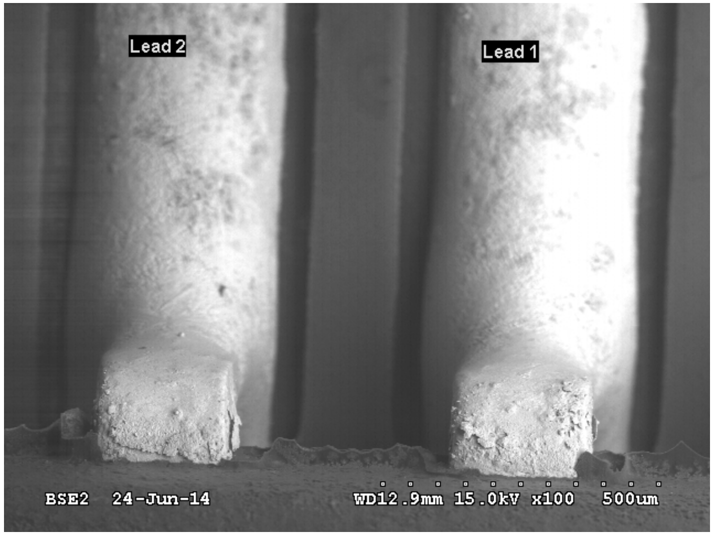

Lead 1
Lead 2
BSE2 21-Aug-14
WD14.8mm 20.0kV x100 500um


BSE2 21-Aug-14
WD14.9mm 20.0kV x3.0k 10um


BSE2 21-Aug-14
WD14.9mm 20.0kV x3.0k 10um

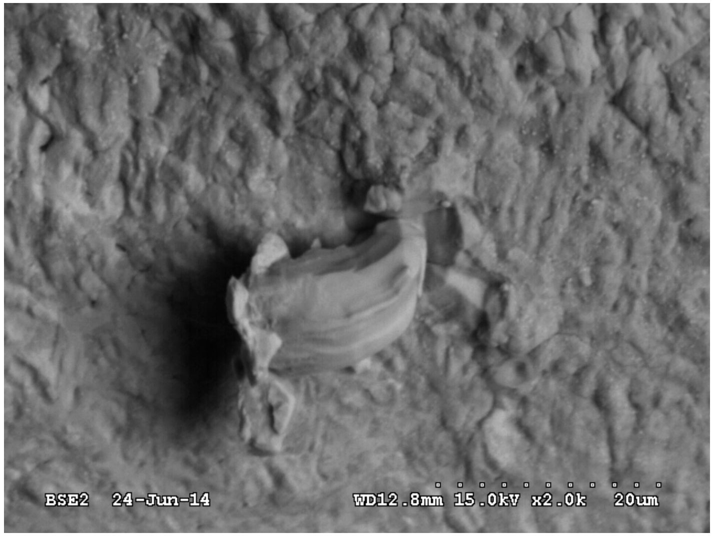

BSE2 21-Aug-14
WD15.0mm 20.0kV x3.0k 10um

SOT6 1-1


Lead 2
Lead 1
BSE2 24-Jun-14
WD12.9mm 15.0kV x100 500um


BSE2 26-Jun-14
WD11.2mm 15.0kV x1.8k 25um


BSE2 24-Jun-14
WD12.9mm 15.0kV x3.0k 10um


BSE2 24-Jun-14
WD12.8mm 15.0kV x2.0k 20um

Summary of Inspection

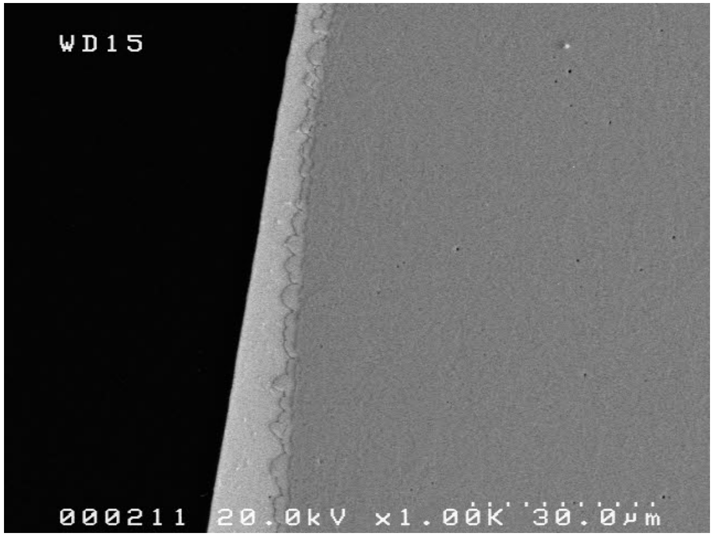
After ~16,000 hours of 25°C / 85% RH

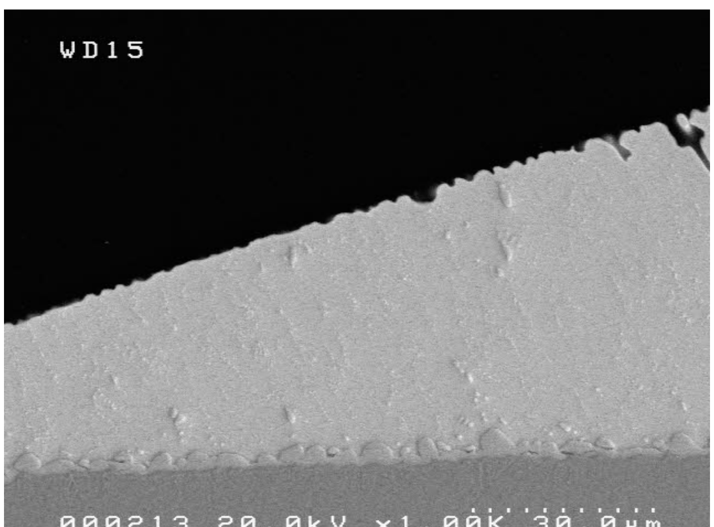
- Cu194 (SOT5) showed more whisker growth than Alloy 42 (SOT3 and SOT6)
- Clean Assemblies showed little to no whisker growth
- Contaminated Assemblies showed significant whisker growth

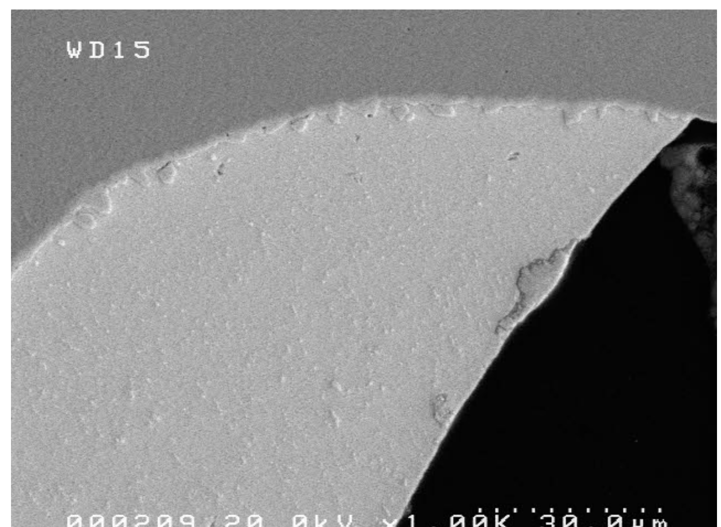
Cross Sectional Analysis

- Performed on SOT5 (Cu194) after 16,000 hours of testing was complete
- Oxide Structure Inspected

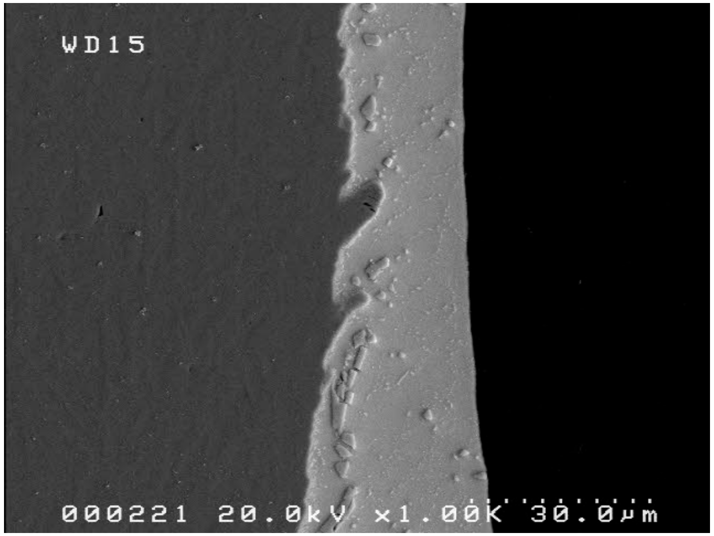
SOT5 0-0 Little to No Oxide

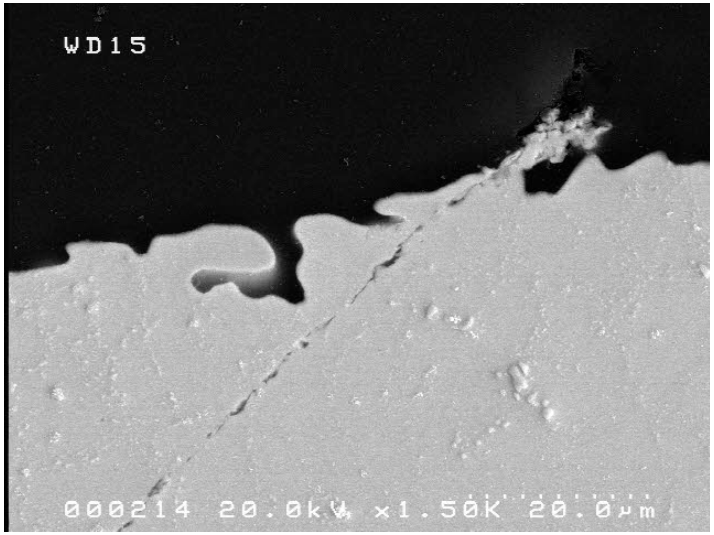






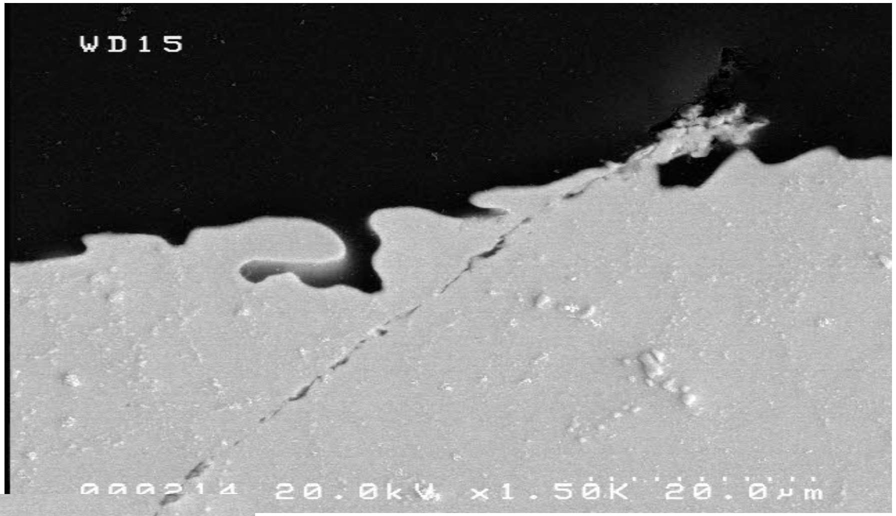
SOT5 1-0

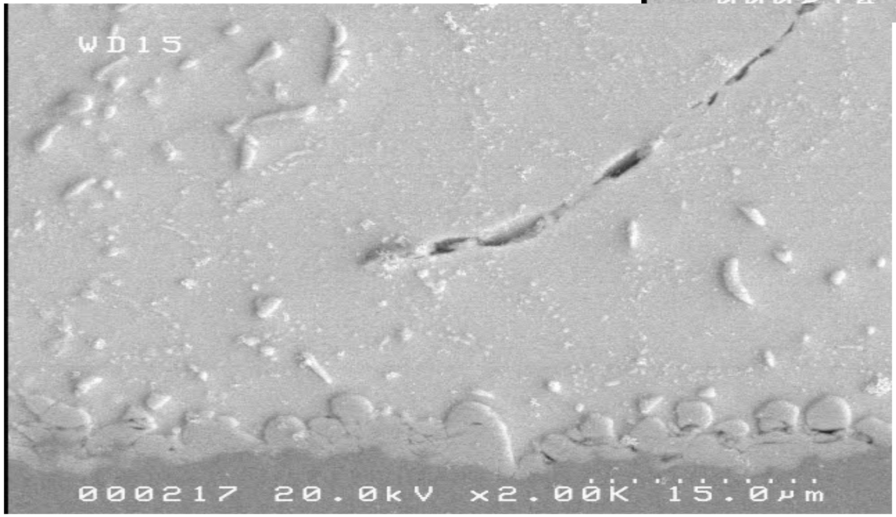


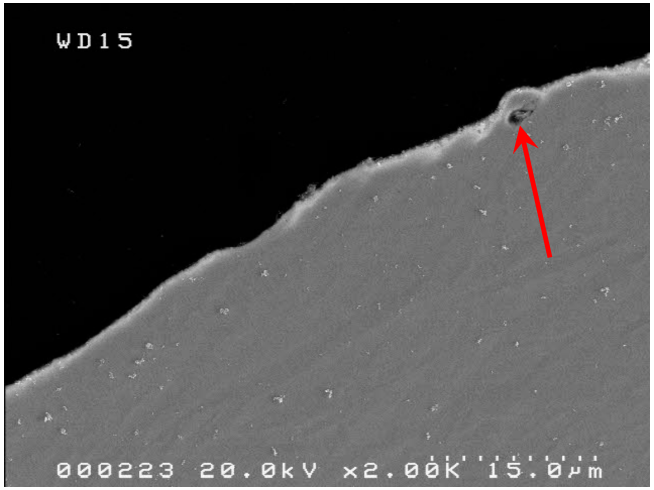


- Little to No Surface Oxide
- Oxide in Bulk Solder in Interdendritic Spaces

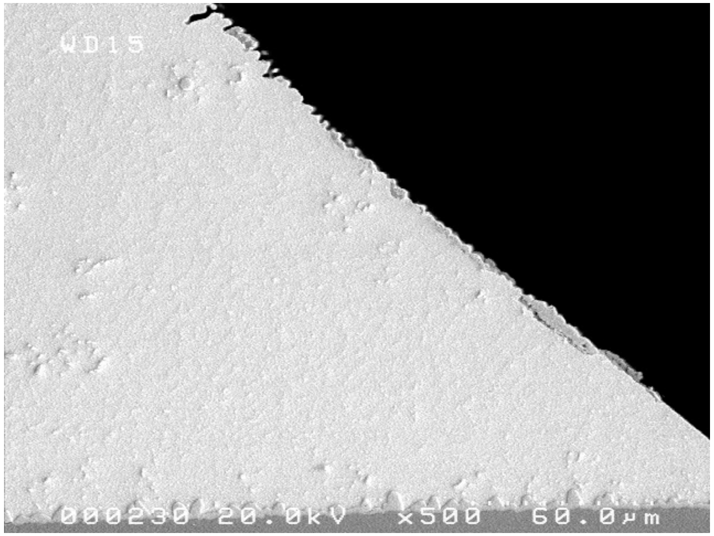
SOT5 1-0

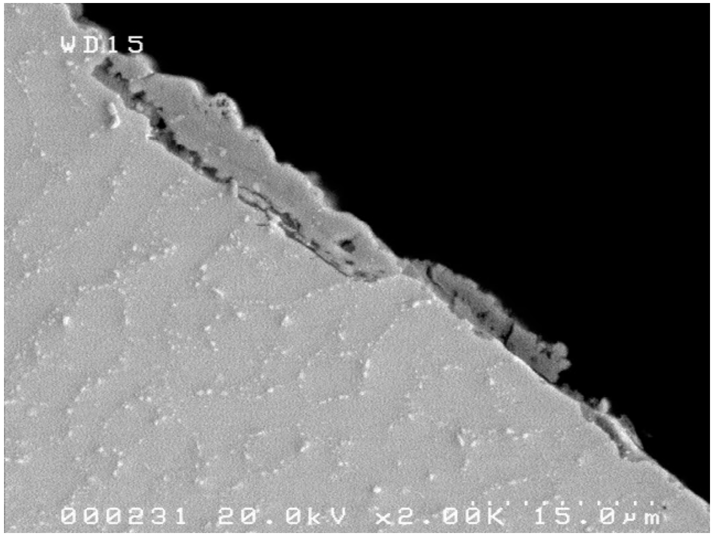

WD15
20.0kV x1.50K 20.0µm

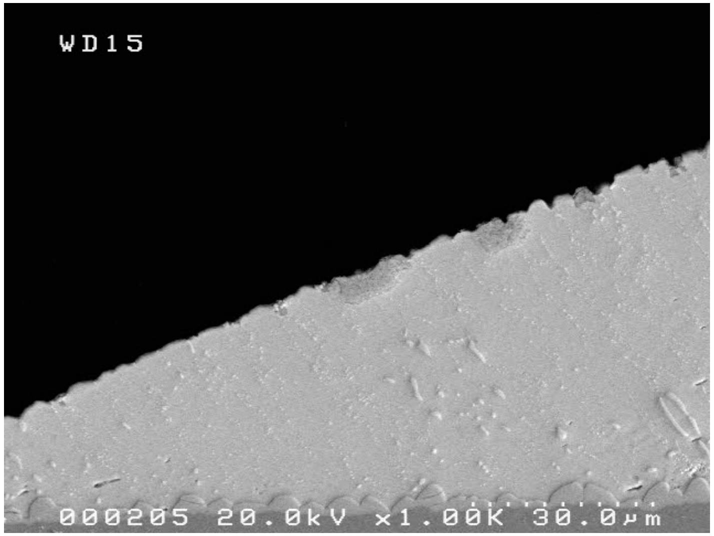

WD15
000217 20.0kV x2.00K 15.0µm

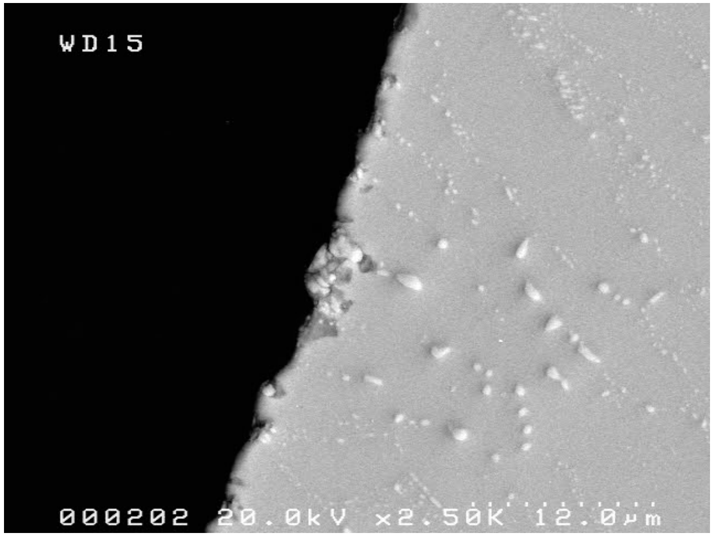

WD15
000223 20.0kV x2.00K 15.0µm

SOT5 0-1

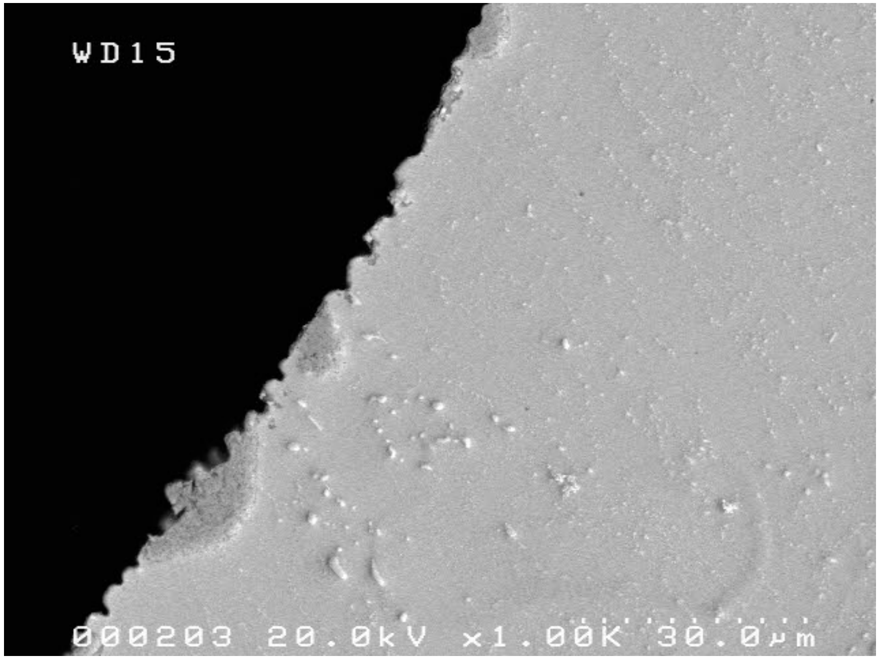

WD15
000230 20.0kV x500 60.0μm

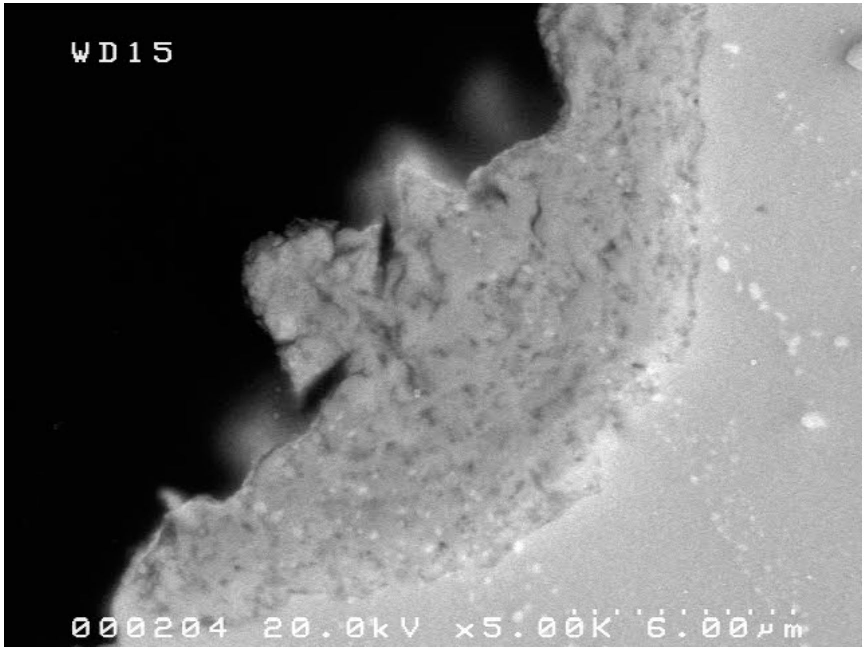

WD15
000231 20.0kV x2.00K 15.0μm


WD15
000205 20.0kV x1.00K 30.0μm

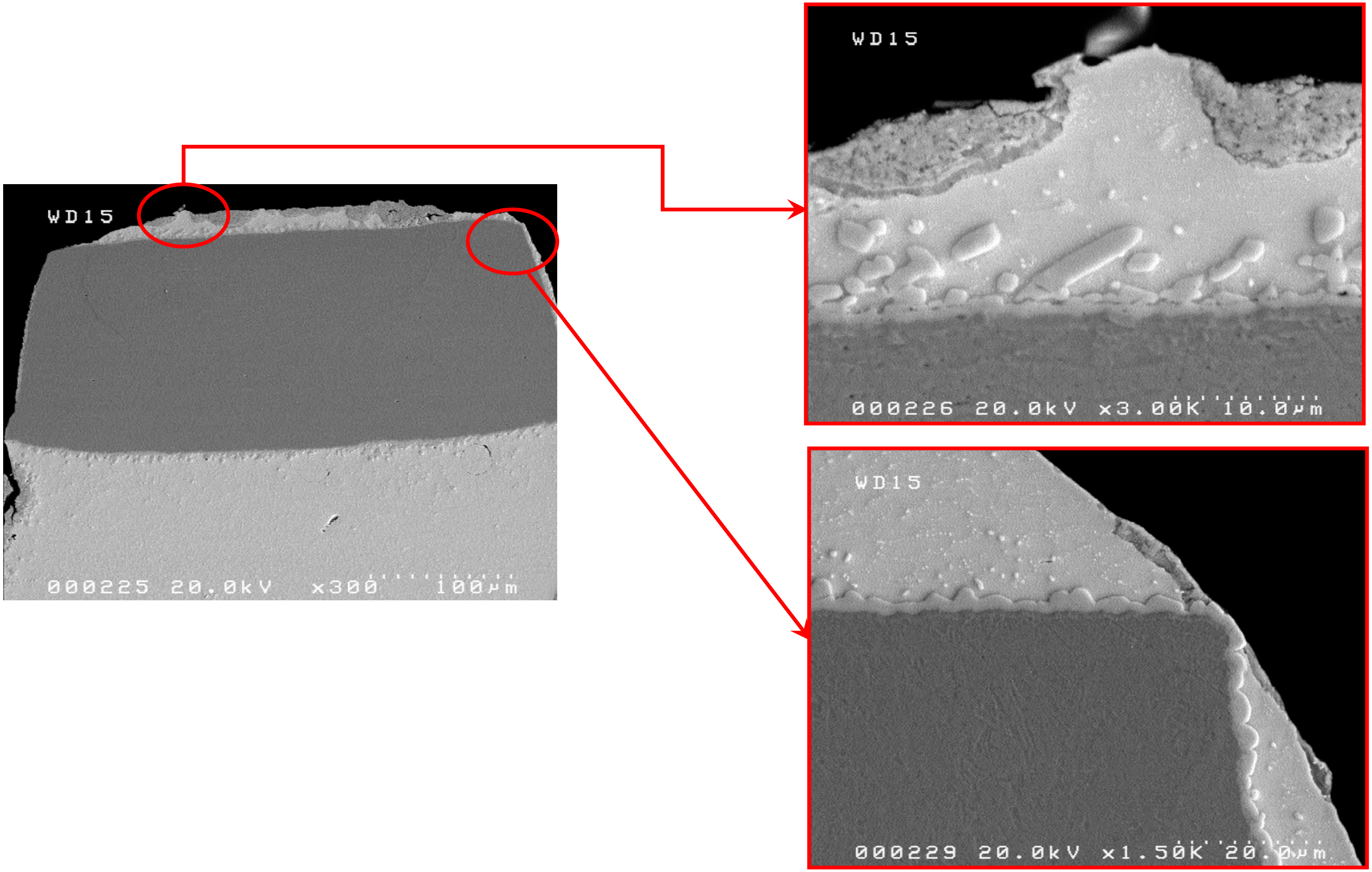

WD15
000202 20.0kV x2.50K 12.0μm

SOT5 0-1

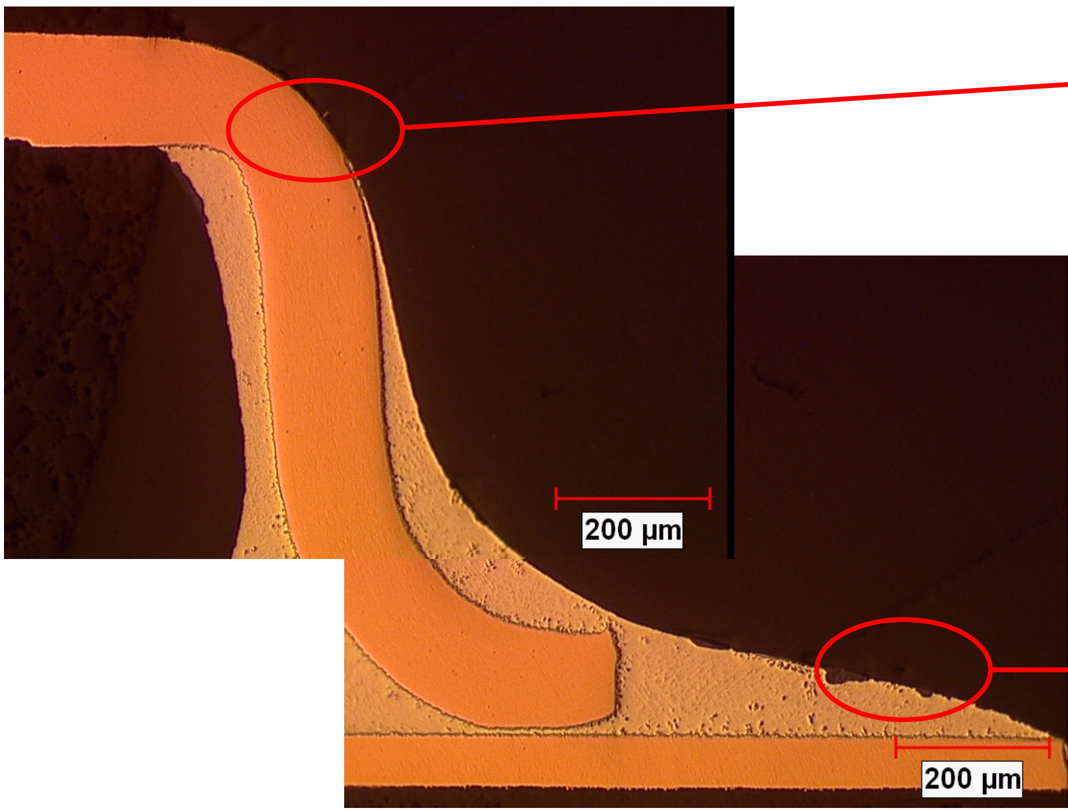

WD15
000203 20.0kV x1.00K 30.0μm

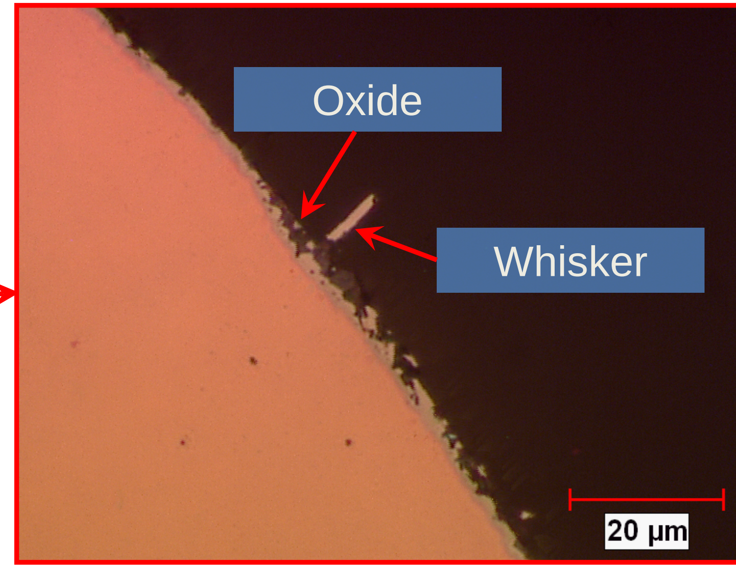

WD15
000204 20.0kV x5.00K 6.00μm

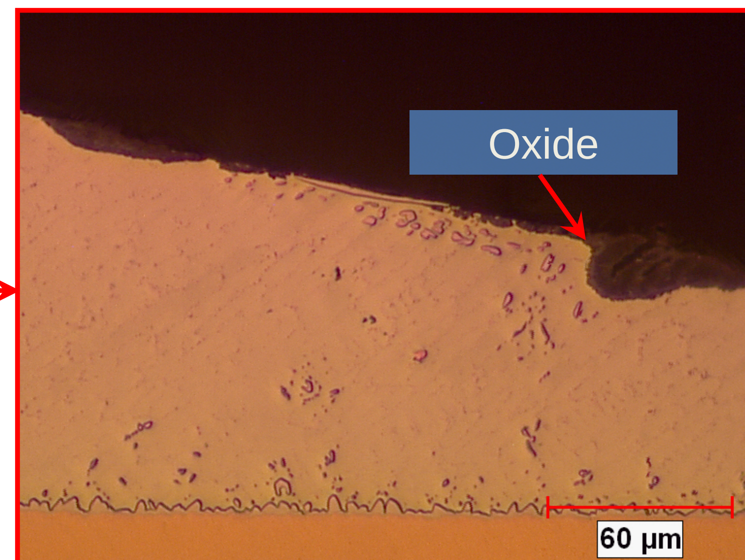
SOT5 0-1


WD15
000225 20.0kV x300 100μm
WD15
000226 20.0kV x3.00K 10.0μm
WD15
000229 20.0kV x1.50K 20.0μm

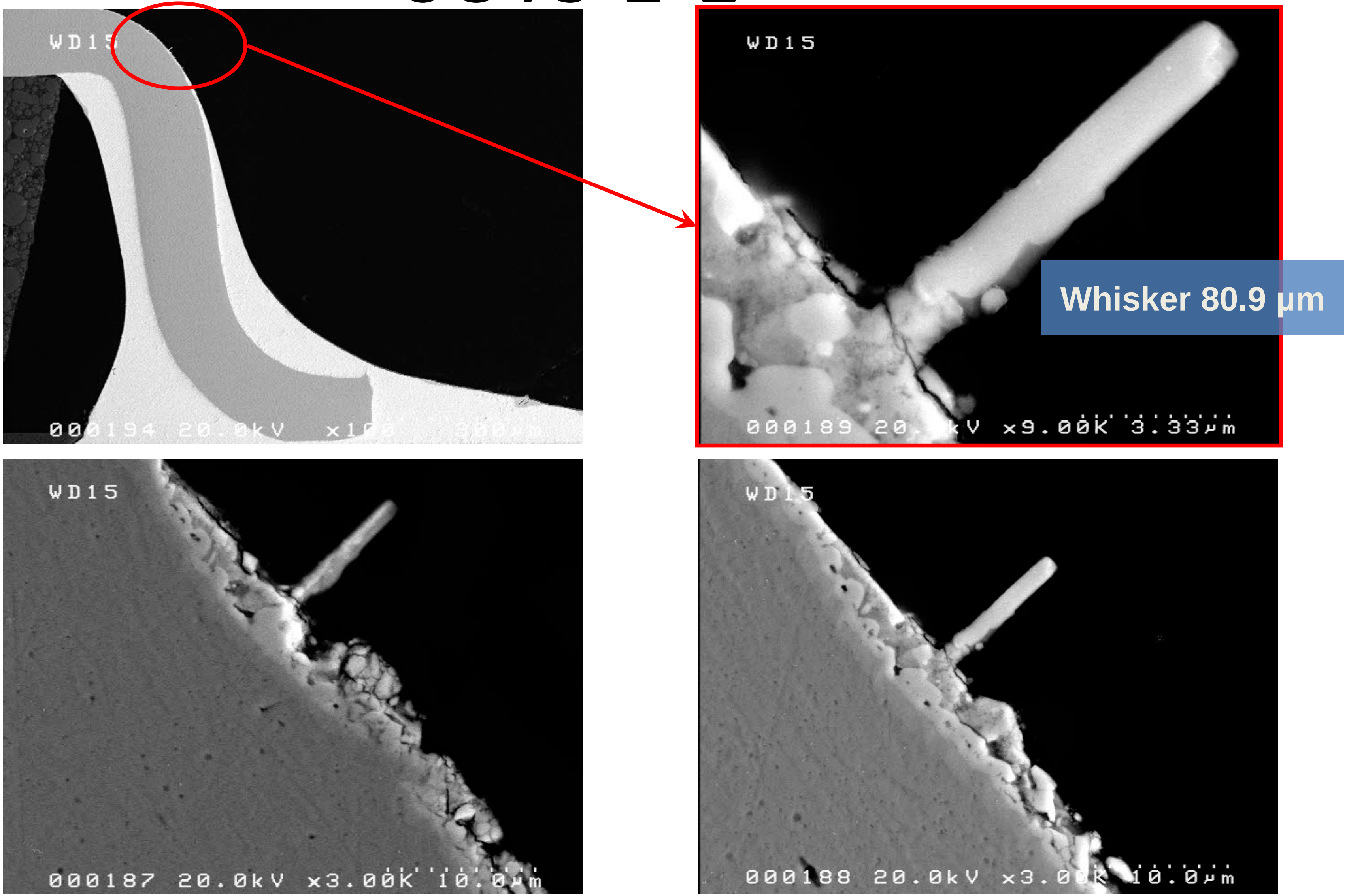
SOT5 1-1



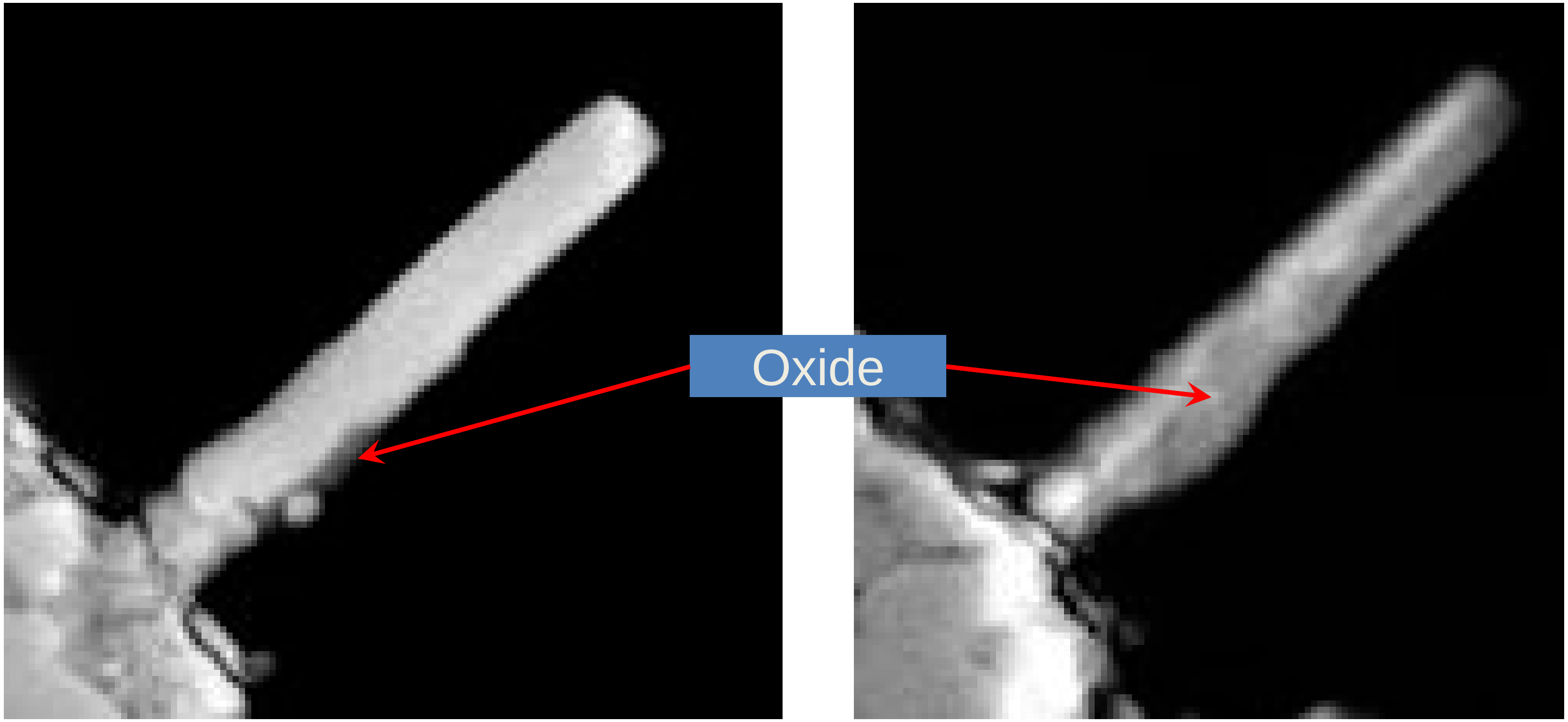




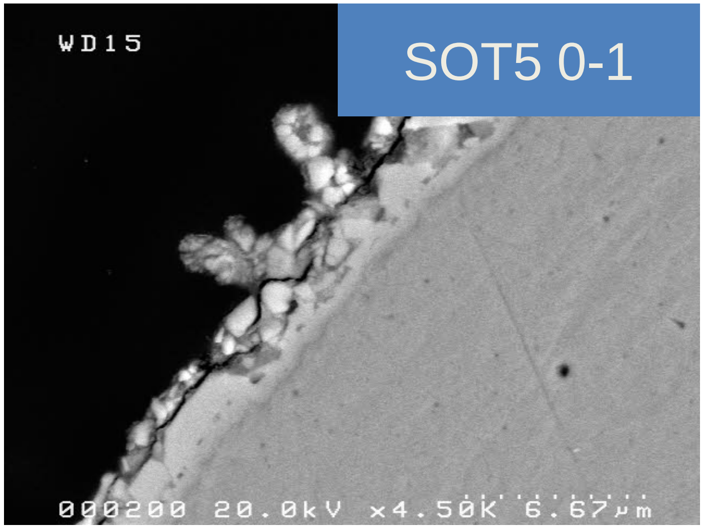
SOT5 1-1

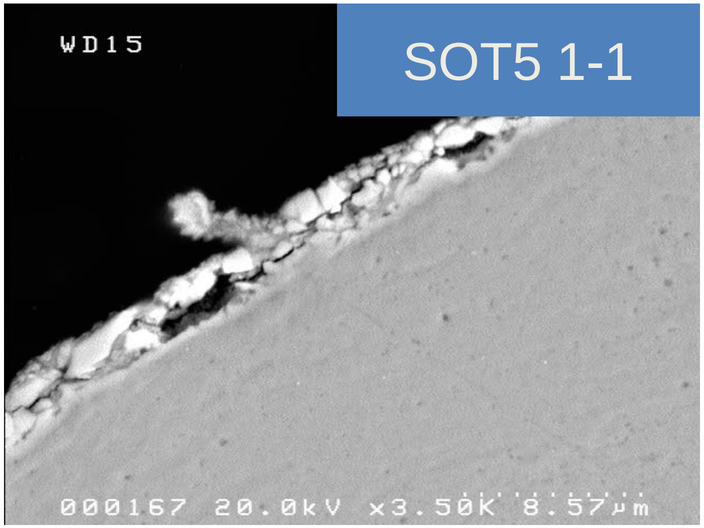

WD15
Whisker 80.9 µm
WD15
000187 20.0kV x3.00K 10.0µm
WD15
000188 20.0kV x3.00K 10.0µm

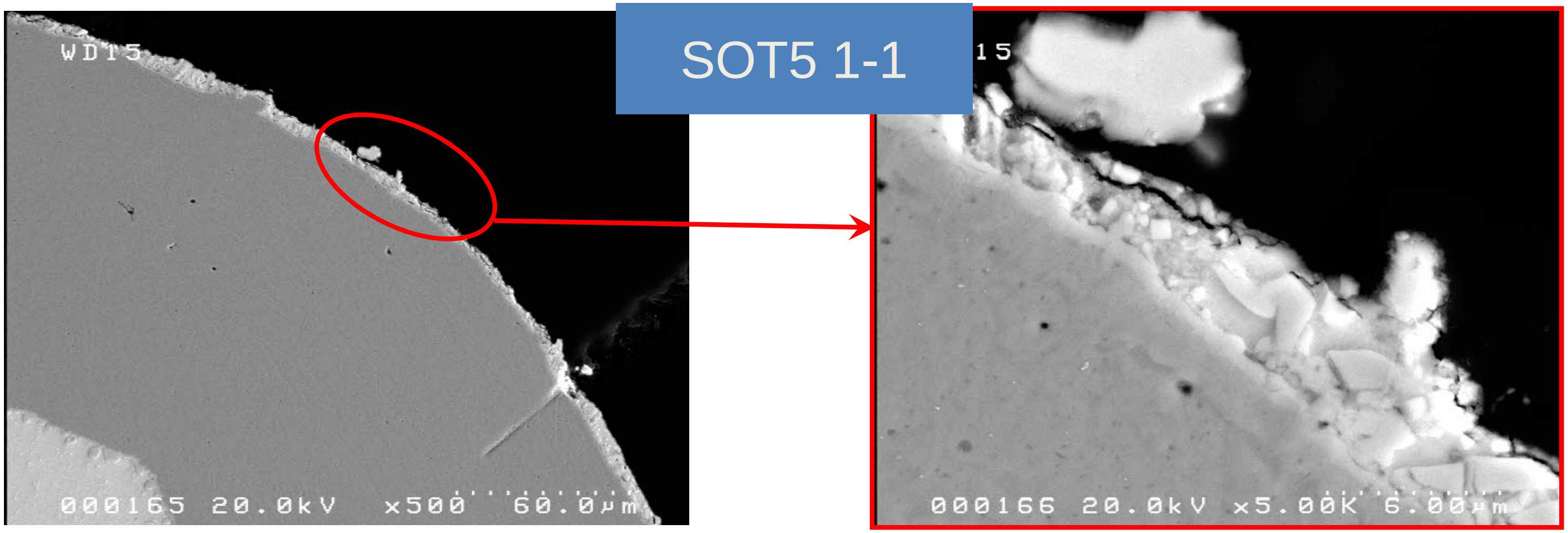
SOT5 1-1



Oxidized Whiskers







Summary of Cross Sectioning

After ~16,000 hours of 25°C / 85% RH

- Contaminated Assemblies Resulted in Significant Surface Oxide
- Oxide Can Extend to Whisker
- Contaminated Components Resulted in Oxidation within the Bulk Solder, in Interdendritic Spaces

Acknowledgement

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- Prakash Kapadia and Jie Qian for developing cleaning and contaminating methods
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Thank you!

QUESTIONS???