Tin Whisker Group Teleconference
January 11, 2012

Assessment of Tin Whisker Mitigation for Conformally Coated SnPb Assemblies

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What is CALCE?

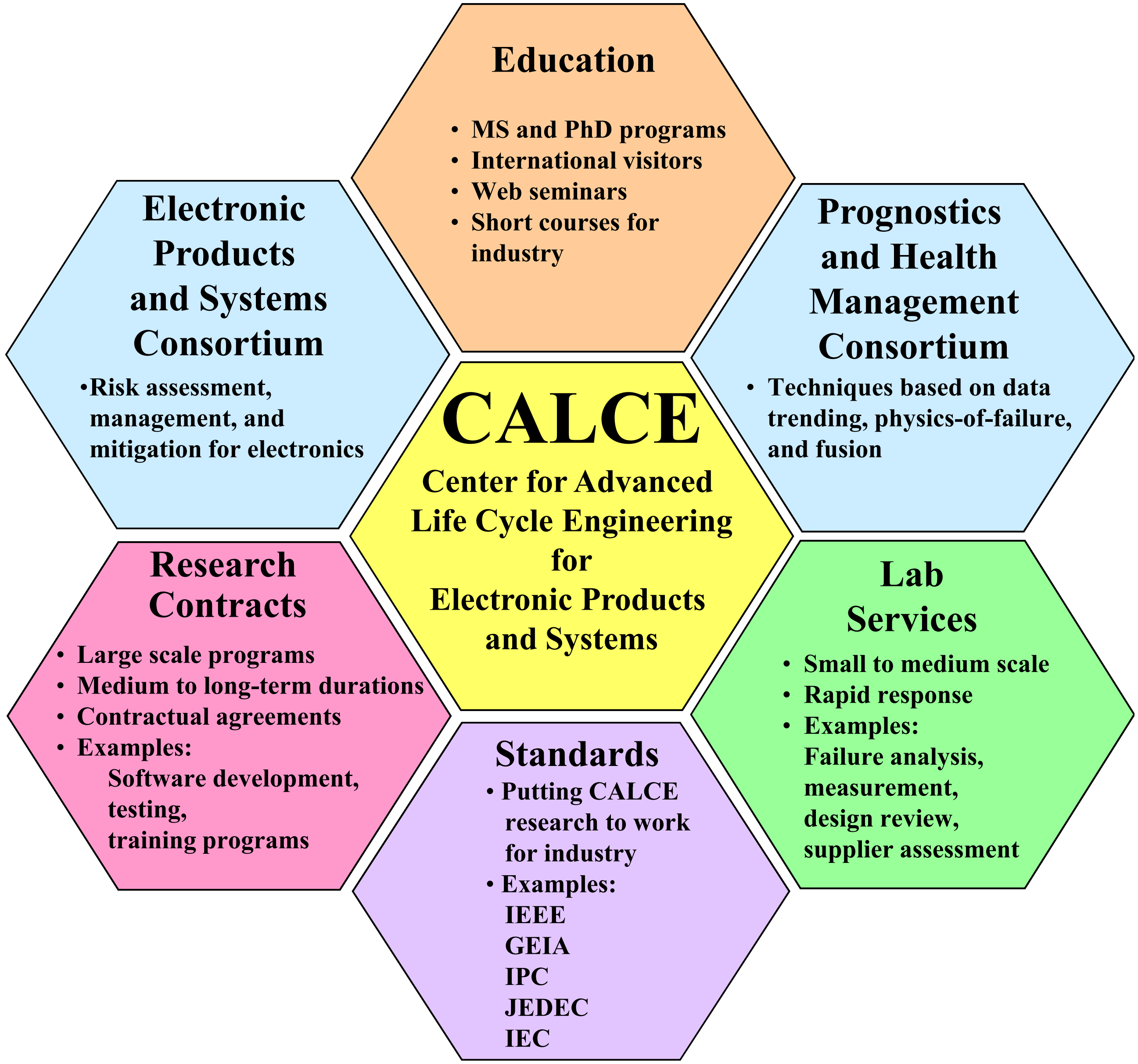
http://www.calce.umd.edu

Center for Advanced Life Cycle Engineering (founded 1987) is dedicated to providing a knowledge and resource base to support the development and sustainment of competitive electronic components, products and systems. Focus areas:

- Physics of Failure
- Design of Reliability
- Accelerated Qualification
- Supply-chain Management
- Obsolescence
- Prognostics

Center Organization

16 research faculty
5 technical staff
40+ PhD students
20+ MS students
11 visiting scholars



Whisker Related CALCE Symposia and Workshops

- 6th International Symposium on Tin Whiskers (planning stage UK 2012)
- 5th International Symposium on Tin Whiskers (2011)
- 4th International Symposium on Tin Whiskers (2010)
- 3rd International Symposium on Tin Whiskers (Denmark 2009)
- Workshop on Testing of Lead-free Electronic Assemblies (2009)
- Symposium on Reprocessing Tin Whisker Mitigation and Assembly Rework (2008)
- 2nd International Symposium on Tin Whiskers (Tokyo 2008)
- Lead-free and Mixed Solder Readiness (2007)
- Symposium for RoHS Impact on Rework/Repair/Reprocessing (2007)
- 1st International Symposium on Tin Whiskers(2007)

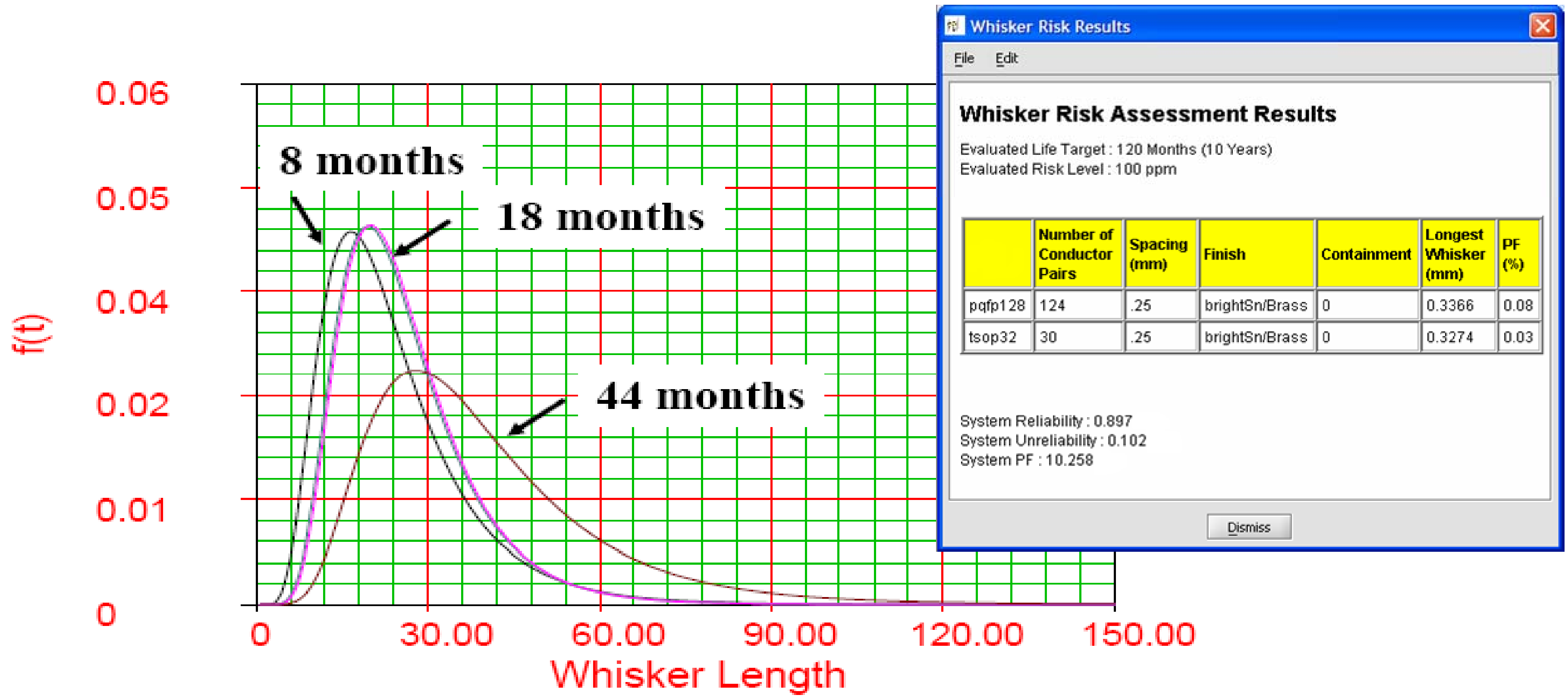
CALCE Tin Whisker Initiatives

- Tin whisker research started in 2002, under CALCE long-term lead-free program
- History channel segment on risks due to tin whiskers (March 22, 2006, Modern Marvels)
- Research results: See CALCE Tin Whisker Website:

  www.calce.umd.edu/tin-whiskers
  - Whisker growth characteristics (Length, density, growth angle, growth rate)
  - Tin whisker risk assessment software - quantitative 'risk assessment' providing a dynamic risk trend with time
  - Tin whisker mitigation guide
  - Substrate effects, annealing
  - Test methods (Sequential temperature cycling/damp heat, mechanical loading)
- Current whisker mitigation studies
  - Mitigation methods (Conformal coating, photosintering)
  - Electrical shorting potential

CALCE Tin Whisker Risk Calculator

Tin whisker risk is estimated using whisker growth statistics (length and density), and component and assembly conductor materials and dimensions. Distribution of whisker lengths on tin plated surfaces found to follow a lognormal distribution.



Whisker Risk Assessment Results

Evaluated Life Target : 120 Months (10 Years)
Evaluated Risk Level : 100 ppm

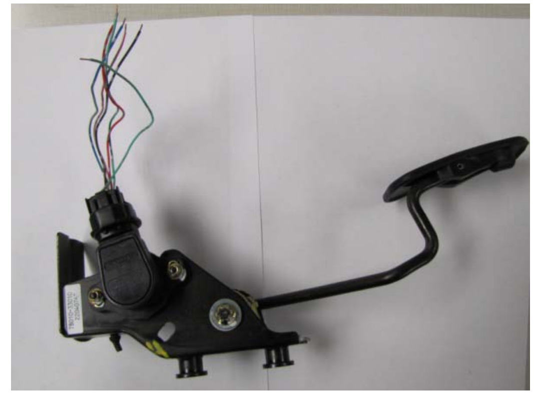
	Number of Conductor Pairs	Spacing (mm)	Finish	Containment	Longest Whisker (mm)	PF (%)
pqfp128	124	.25	brightSn/Brass	0	0.3366	0.08
tsop32	30	.25	brightSn/Brass	0	0.3274	0.03

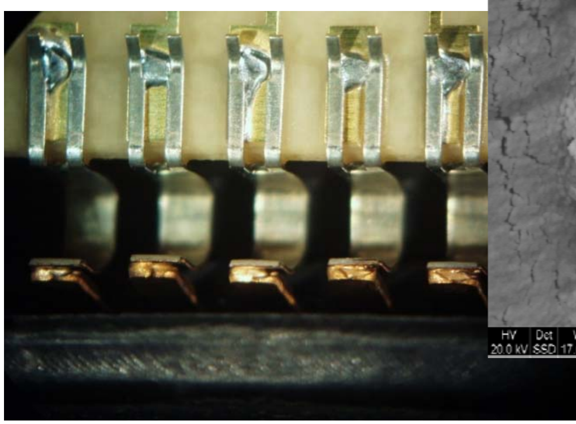
System Reliability : 0.897
System Unreliability : 0.102
System PF : 10.258

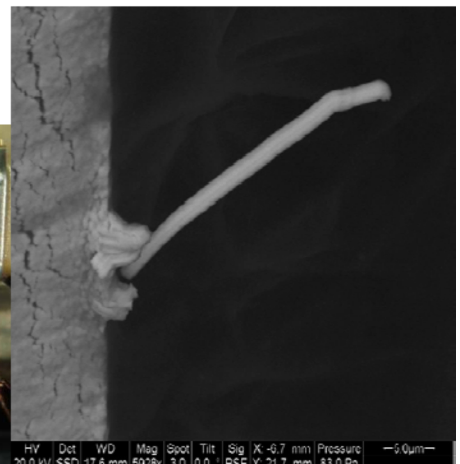
More Information at
http://www.calce.umd.edu/software/whiskerrisksoftware.htm

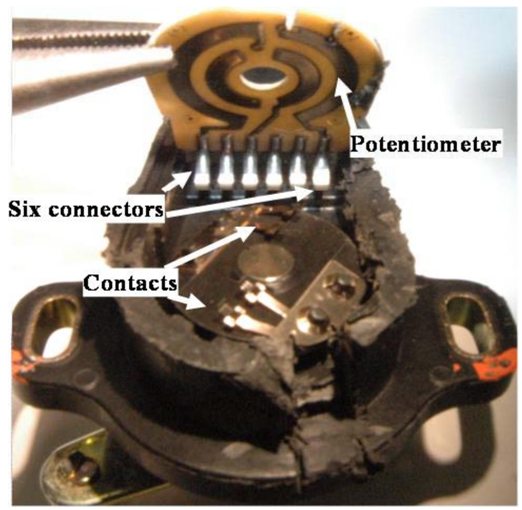
Whisker Failure Risk Identified in Recent CALCE Publication

In a publication by Sood et. al, a tin finished feed through connector for the pedal assembly system of a Toyota vehicle was found to have tin whiskers. Using the CALCE Tin Whisker Risk Calculator, the probability of a tin whisker creating an unintended short was estimated to be 140/1 million.





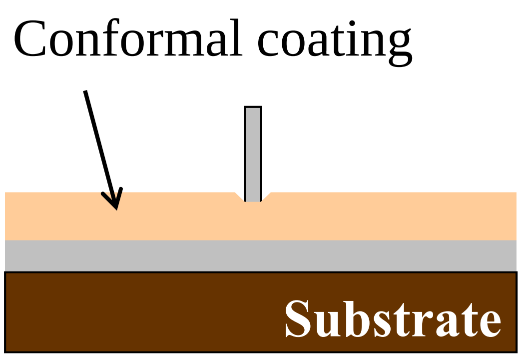




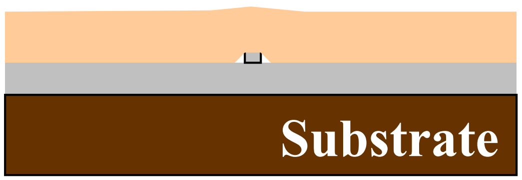
B. Sood, M. Osterman and M. Pecht, **Tin Whisker Analysis of Toyota's Electronic Throttle Controls**, *Circuit World*, Vol. 37, No. 3, 2011, pp. 4–9

Conformal Coating as a Tin Whisker Risk Mitigation Strategy

- Tin whiskers are hair-like crystalline structures that may cause electrical shorting if bridging between adjacent conductors.
- Conformal coatings are thin polymeric layers, designed to protect the surfaces from harsh environments (e.g. moisture and chemicals).
- In terms of tin whisker mitigation, a conformal coating may prevent whiskers from contacting a coated surface and contain whiskers under the coated surface.
- However, past work indicates that tin whiskers may penetrate conformal coatings and present a shorting risk.
- Most studies of conformal coatings as tin whisker mitigation strategy have used coupons with flat surfaces - such surfaces would have near perfect coverage.



Prevent Contact



Contain Whisker

Motivations & Objectives

- Motivations
  - Conformal coatings served well in whisker containing [1].
  - Past work indicates that tin whiskers may penetrate conformal coating and present a failure risk [2].
  - Most studies of conformal coating as a tin whisker mitigation strategy have used coupons with flat surfaces - such surfaces would have near perfect coverage.
- Objectives
  - Examine the propensity of whisker formation on select assembled surface mount parts with Sn-Pb solder.
  - Examine the effectiveness of various conformal coating systems to contain tin whisker growth on select surface mount assembled parts.

1. H. Leidecker, and J.S. Kadesch, "Effects of Uralane Conformal Coating on Tin Whisker Growth", Proceedings of IMAPS Nordic, The 37th IMAPS Nordic Annual Conference, pp. 108-116, September, 10-13, 2000
2. T. A. Woodrow, E. A. Ledbury, “Evaluation of conformal coatings as a tin whisker mitigations strategy, part II”, Proceedings of SMTA International Conference, 2006

Materials Under Test

- Test Specimens: 184 Quad Flat Packages (QFP)
  - Alloy42 lead material
  - Sn surface finish
  - 0.34 mm lead spacing
  - Assembled with Sn-Pb solder paste.

- Six conformal coatings were applied
  - Acrylic (AR): Type 1 and Type 2 by machine spray
  - Silicone (SR) by machine spray
  - Polyurethane (UR) by hand spray
  - Parylene (XY) by vapor deposition
  - ALD-Cap O5TA200 (ALD) by vapor deposition
- Some were uncoated for a control

Experimental Matrix

- Coated and non-coated test specimens were separated into two groups to be subjected to environmental loading sequences.

Group 1	TC-A	TC-B	TC-C	TH	
Group 2	TC-A	TC-B	TC-C	MFG	TH

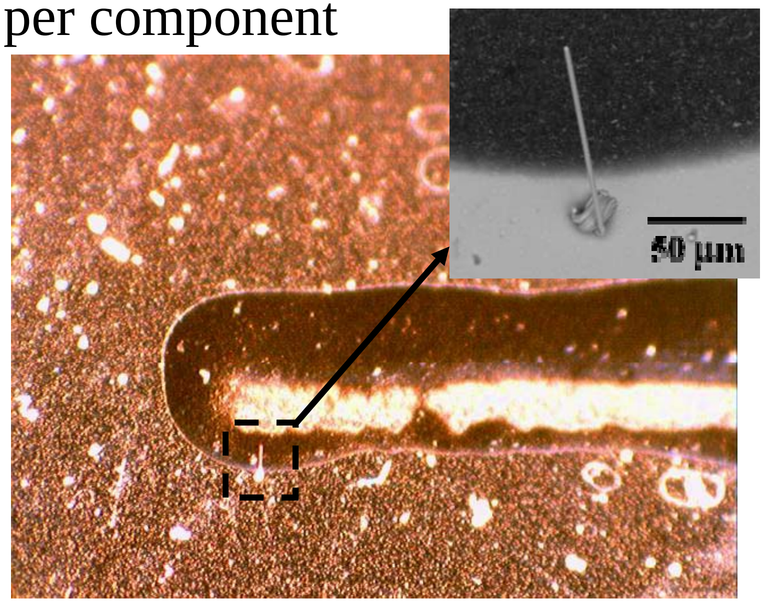
- Loading Cycles
  - TC: Temperature cycling for 100 cycles with 30 min dwells
    Cycle A (-55 °C/20 °C) / Cycle B (-15 °C/60 °C) / Cycle C (20 °C/95 °C)
  - TH: Temperature Humidity with 50 °C/50% RH for 200 hrs
  - Mixed Flowing Gases (MFG) for 48 hrs (EIA-364-TP65A class IV)

Class	Temp °C	RH (%)	H_2S (ppb)	Cl_2 (ppb)	NO_2 (ppb)	SO_2 (ppb)
IV	50 ± 2	75 ± 2	200 ± 20	30 ± 5	200 ± 50	200 ± 50

  - Conducted the two loading cycles

Whisker Inspection Procedure

- Prior to environmental exposure and after environmental exposure specimen were subjected to the follow inspection procedure:
- Area identified under optical microscope as possible whisker site examined under Scanning Electron Microscope (SEM) to report whisker length and density information.
- If no whisker growth observed during optical inspection with max magnification of 65x, at least one terminal per component inspected using SEM as well as areas of poor coverage or damaged coating.
- Conformal coating coverage and defects, such as peeling and bubbling on front and back of leads examined using SEM, because most conformal coatings do not give adequate coverage on leads.

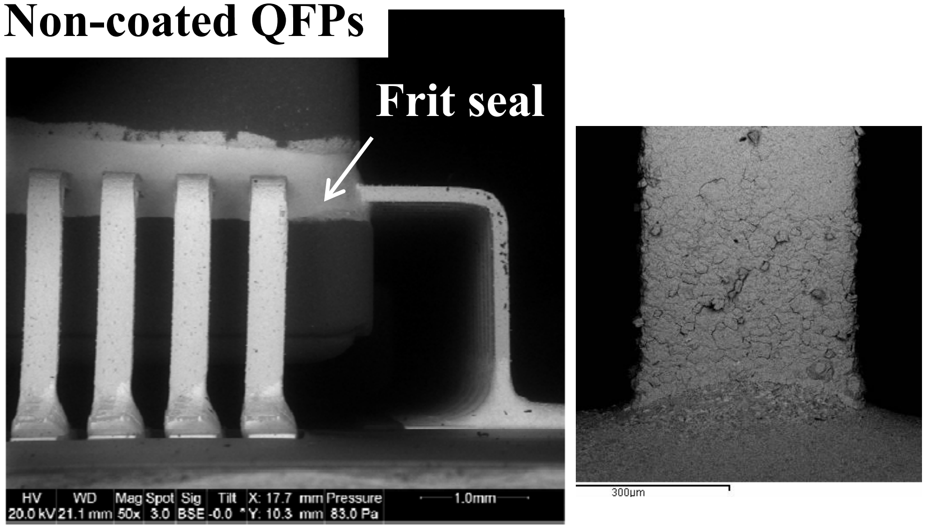


Light reflection from whiskers

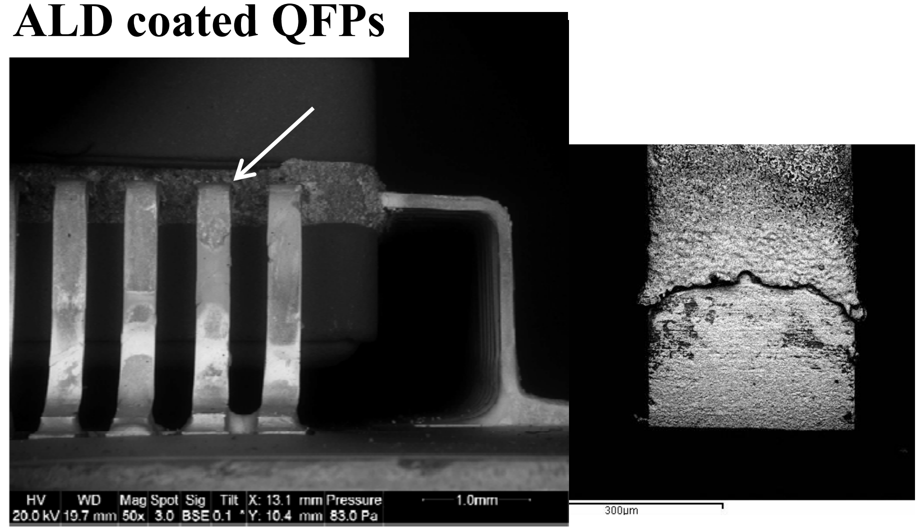
Initial Inspection of Assembled Parts

- No whiskers found on any specimens prior to environmental exposure.
- Pb observed on leads of ALD-coated QFPs because ALD application process damaged Pb-containing frit seal on QFPs.
- All spray-applied conformal coatings had non-uniform coverage of lead edges. Worst coverage exhibited by Acrylic coating Type 1(AR1, machine spray).
- Mechanical surface damage such as scratches observed on both non-coated and conformally coated samples.

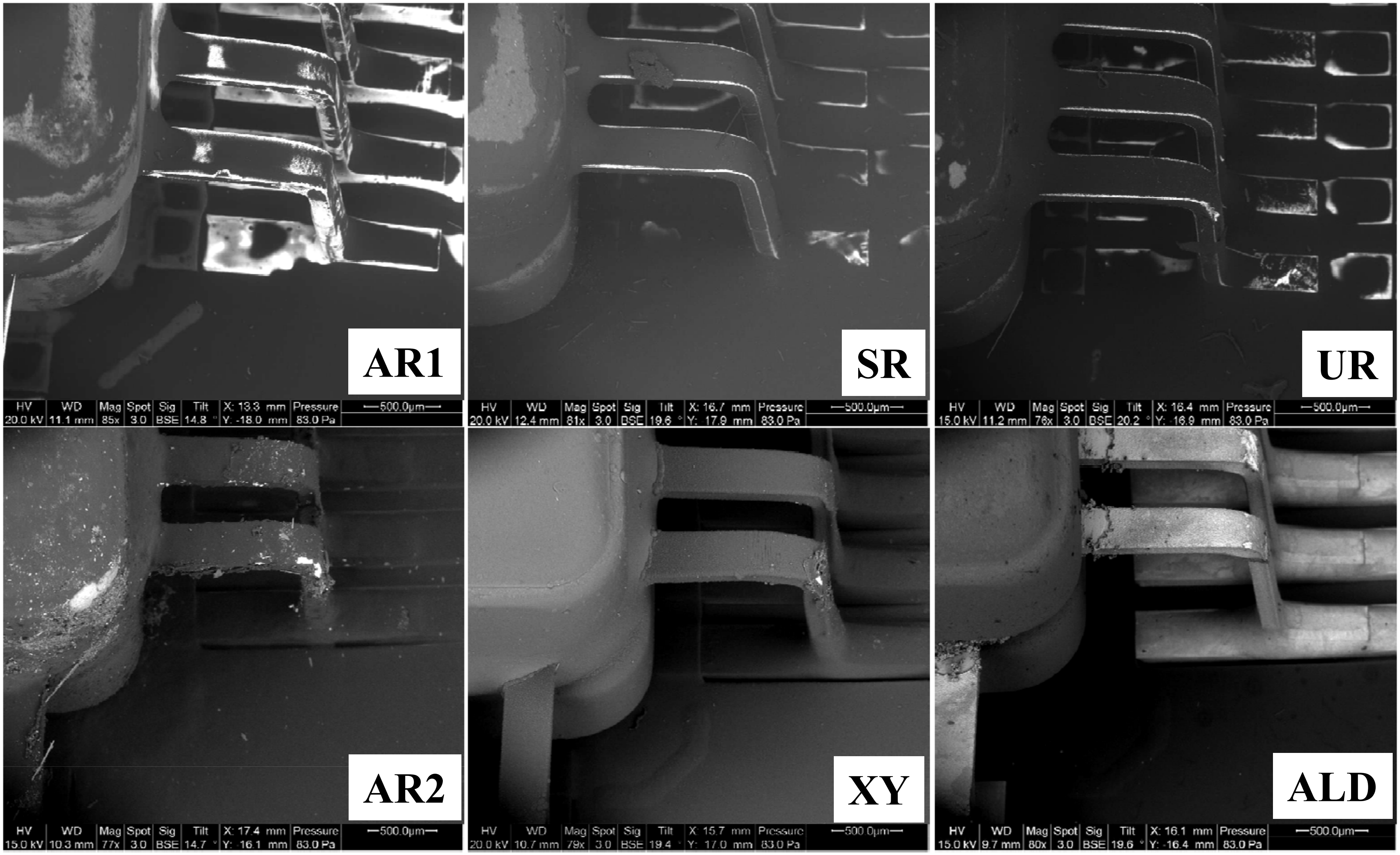
Non-coated QFPs



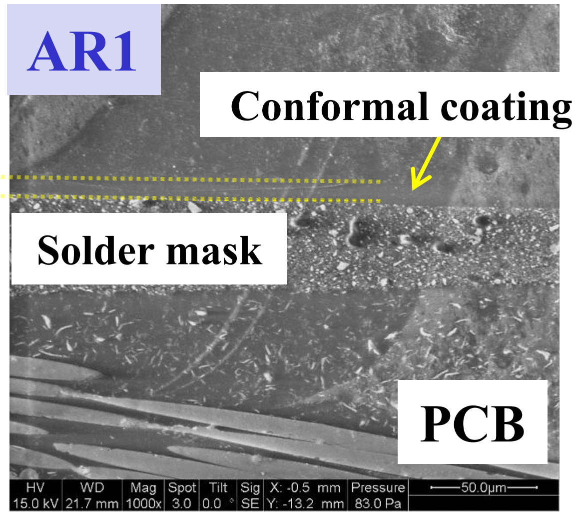
ALD coated QFPs

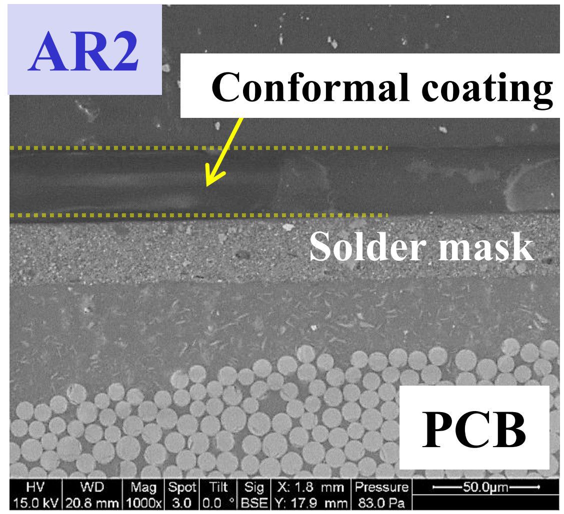


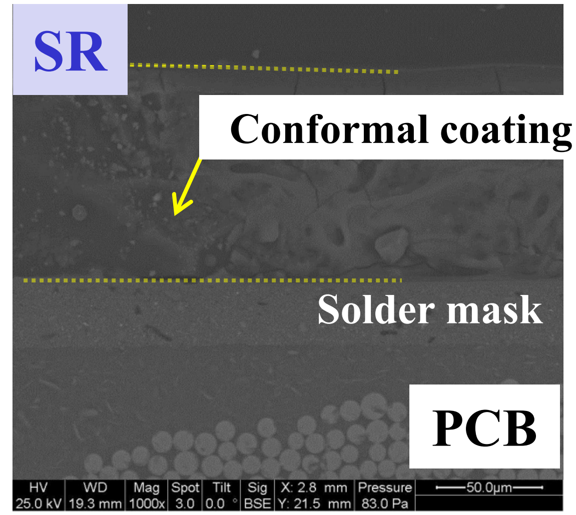
Initial Inspection of Assembled QFPs

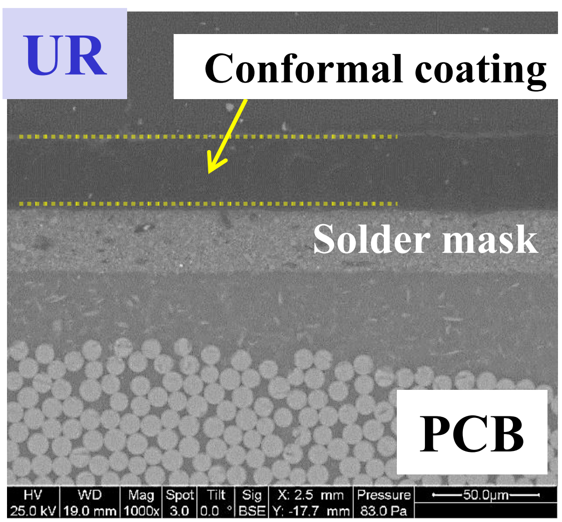


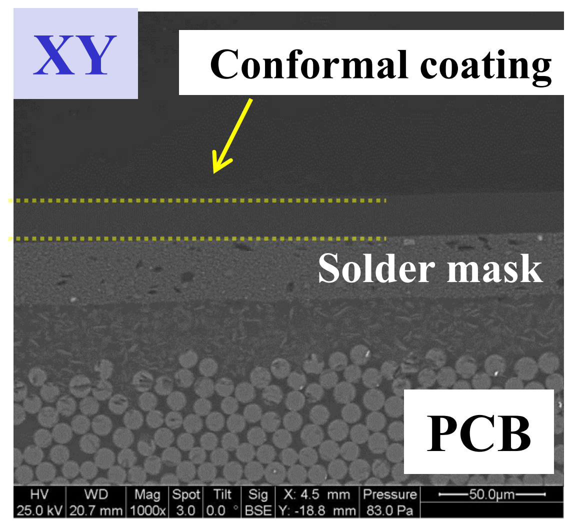
Coating Coverage on Flat Surface





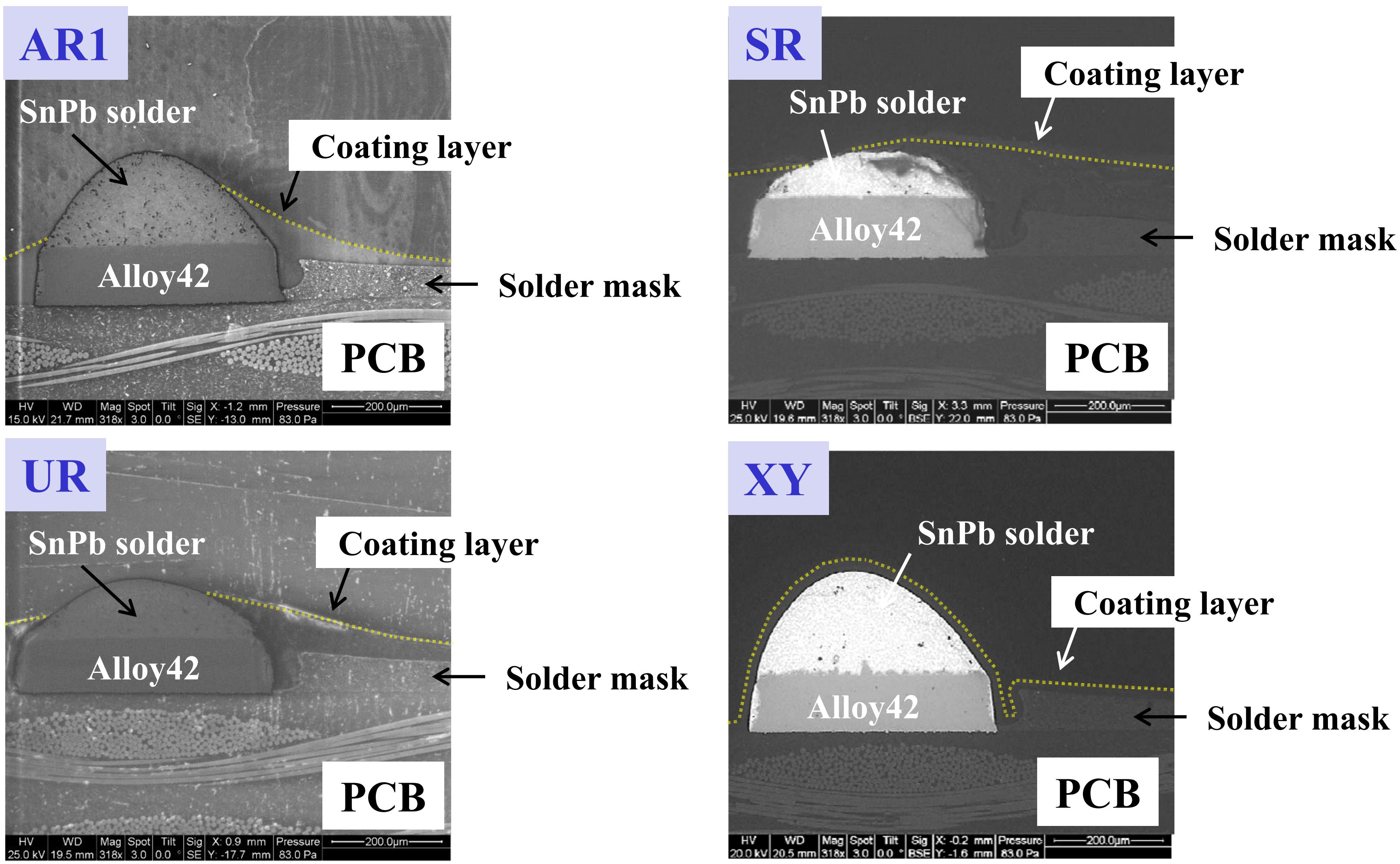






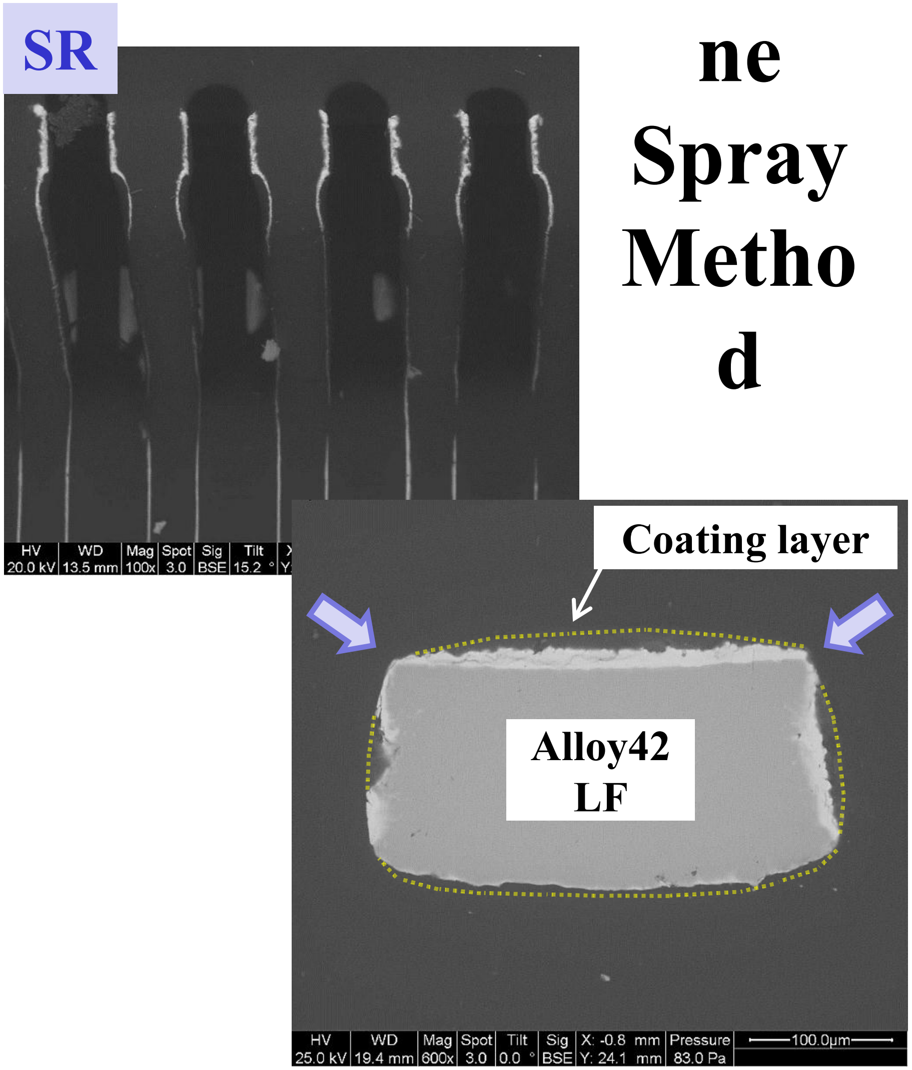
Coating type	Coating thickness (μm)
AR1	9.7
AR2	26.5
SR	100.2
UR	36.5
XY	20.1

Coating Coverage on Leads (Toe)

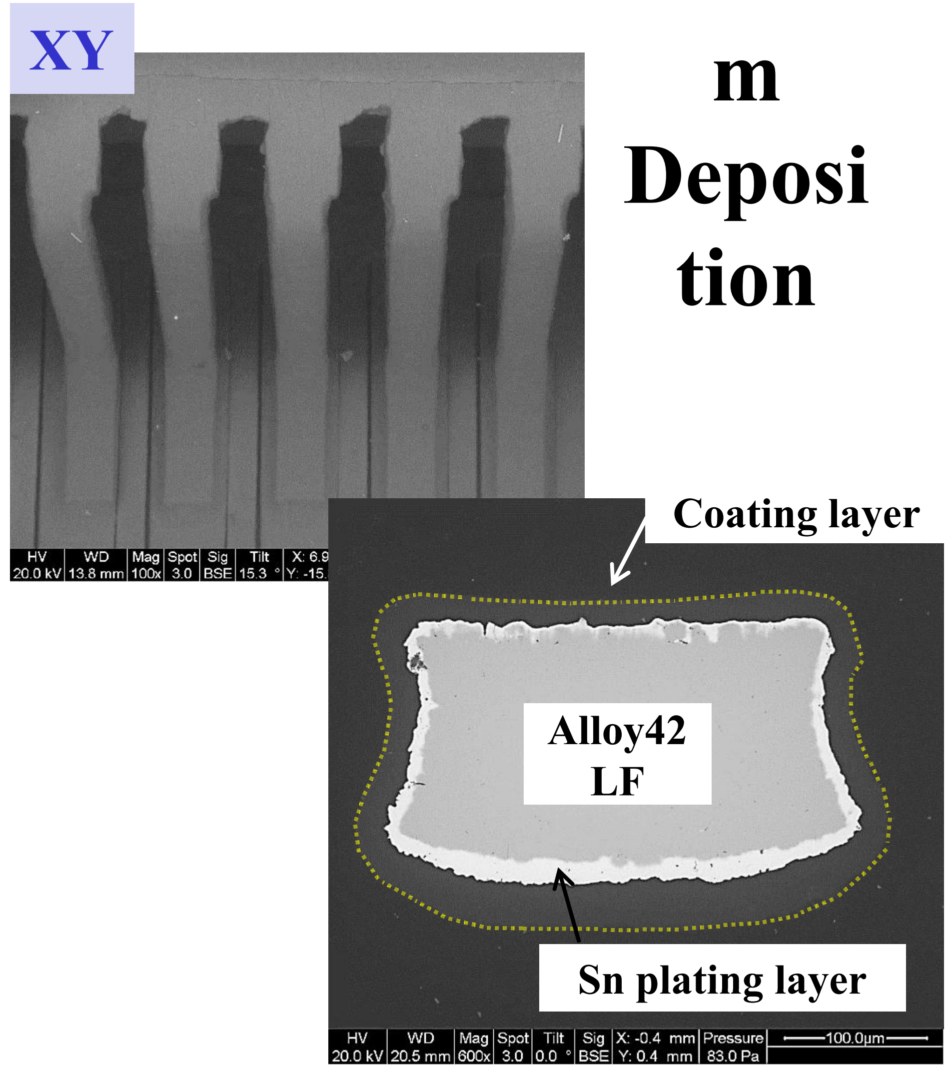


Coating Coverage on Leads (Shoulder)

Machine Spray Method



Vacuum Deposition



Results (all measurements in µm)

		PCB		Lead		
	Application Method	**Solder Mask**	**Conformal Coating**	**Plating Layer**	**Conformal Coating**	**Read As**
AR1	Machine Spray	27.14 (0.26)	20.13 (0.31)	12.29 (0.95)	5.14 (1.61)	Top
				11.51 (0.98)	2.61 (1.26)	Sides
				6.36 (1.78)	-	Bottom
SR	Machine Spray	28.81 (1.88)	66.45 (2.05)	8.74 (1.39)	11.41 (3.39)	Top
				11.90 (3.54)	10.30 (4.15)	Sides
				7.48 (3.62)	11.67 (4.17)	Bottom
UR	Hand Spray	30.88 (0.99)	27.54 (2.71)	16.69 (3.20)	7.96 (1.57)	Top
				15.75 (1.64)	16.35 (1.91)	Sides
				16.48 (0.91)	20.86 (3.93)	Bottom
AR2	Machine Spray	28.42 (1.21)	33.39 (1.32)	10.28 (0.67)	37.241(2.05)	Top
				4.28 (0.90)	3.81 (1.13)	Sides
				2.87 (0.53)	2.61 (0.95)	Bottom
XY	Vacuum Deposition	29.00(1.32)	17.99 (0.44)	3.23 (0.49)	18.09 (2.71)	Top
				14.10 (1.21)	18.32 (1.33)	Sides
				14.64 (2.21)	31.97 (2.03)	Bottom
ALD	Vacuum Deposition	29.60 (0.89)	-	9.12 (0.53)	-	Top
				9.61 (1.28)	-	Sides
				2.32 (0.27)	-	Bottom

Values in the table are averaged and values in parentheses are the standard deviation.
Coating thickness on leads was varied greatly based on position along their circumference.

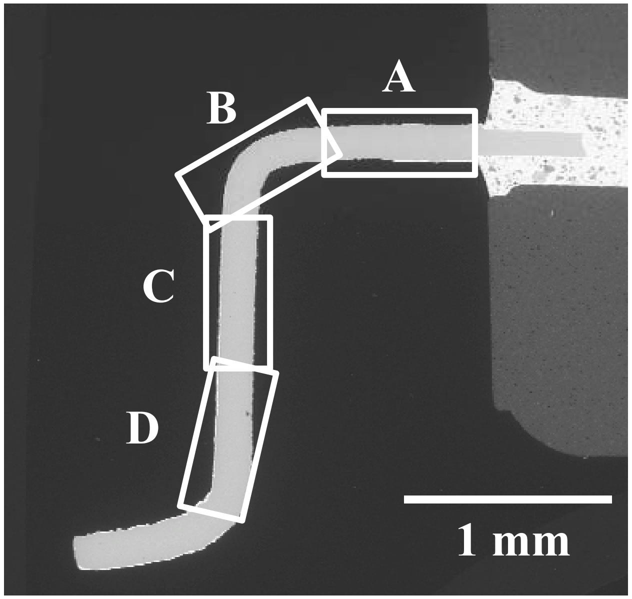
Conformal Coating Thickness Comments

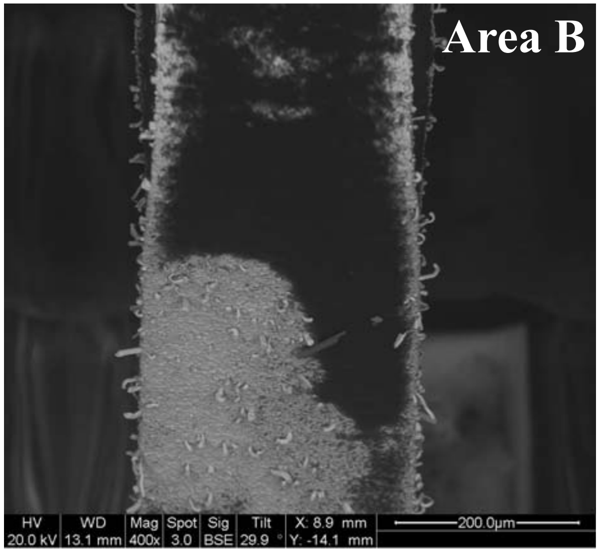
- The coating thickness on the flat surfaces of the PCB was found to be at specification, but was thinner and not uniform on the leads.
- Parylene (XY) was the thickest coating material around the leads and offers better protection against tin whisker growth
- Silicone (SR) provided the thickest coverage of the PCB

Coating Coverage of QFPs

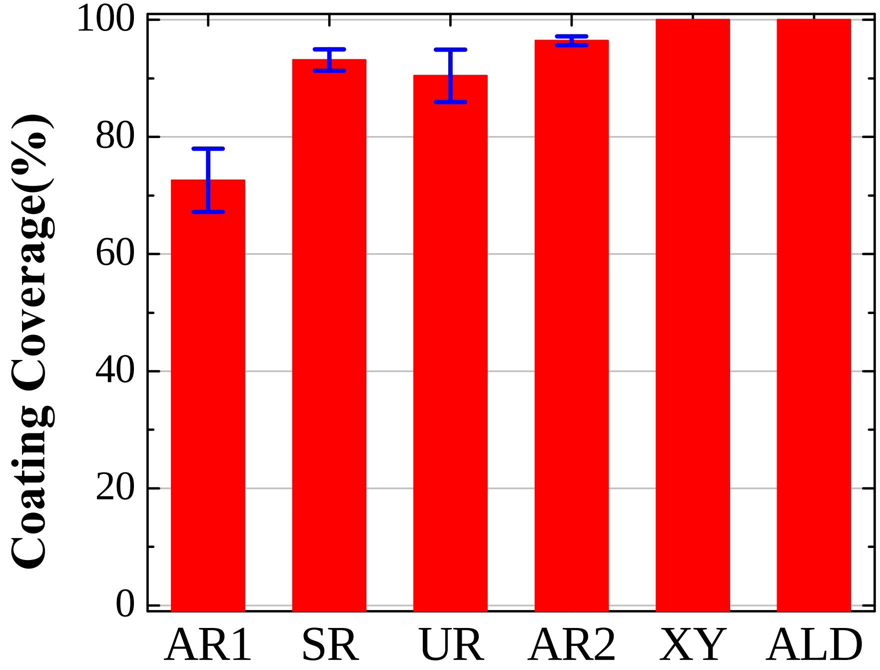
- Surfaces of two leads selected on each side of QFPs (8 total for each component) were evaluated for coating coverage at four areas (A–D).
- In order to evaluate the coating coverage, the surfaces of selected leads were captured via SEM using BSE mode.
- In BSE mode, lighter-colored areas indicate higher atomic number (Z) material – in our case it is the metal finish devoid of coating, or covered with thinner coating.
- Image software was used on BSE images to calculate bright and dark pixels on images.
- Coating coverage calculated by:

$$\text{Coating coverage} = \frac{\text{Dark area}}{\text{Total lead area}}$$





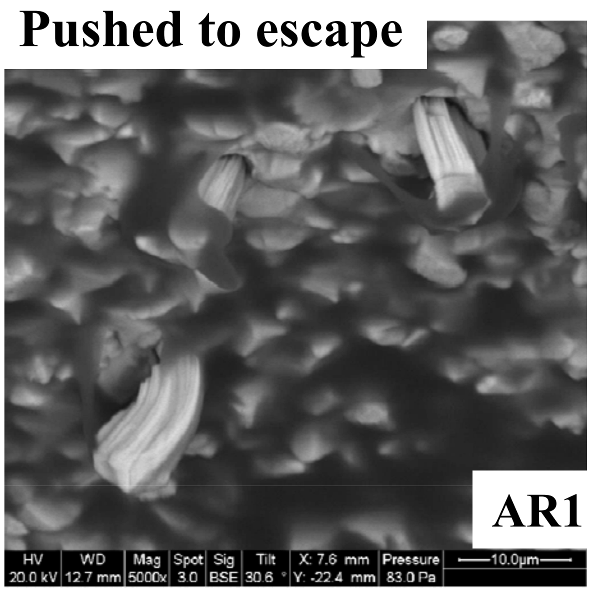
Quantitative Analysis of Coating Coverage

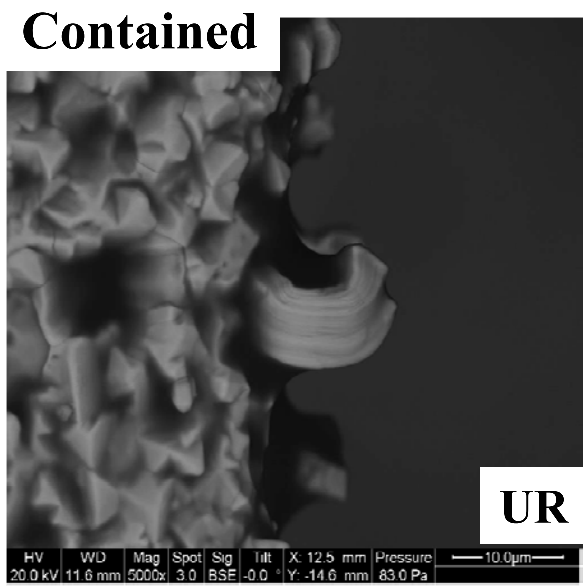


- The result from the quantitative image analysis is consistent with the initial inspections.
- The Acrylic type 1 (AR1) showed the lowest coating coverage with 72.6 % compared to other coatings, while the Parylene C and ALD coating had 100% coating coverage.

Whisker Growth on Conformally Coated QFPs

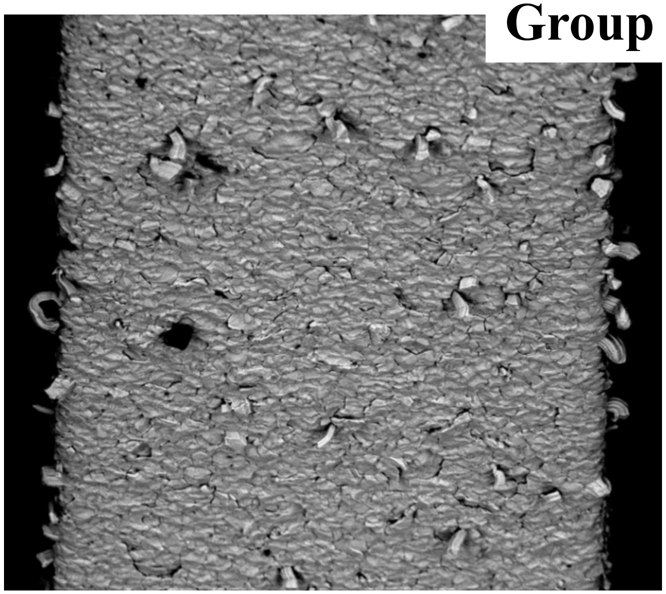
- Whiskers started to grow and penetrate through the AR, SR, UR, and ALD coating after the first accumulated loading cycles.
- Only Parylene C coating did not have the whiskers penetrating coating.
- Most of whiskers grew on areas with relatively thinner coatings or areas with mechanically damaged coating.
- Sn-Pb whiskers observed on QFPs coated with ALD away from solder.





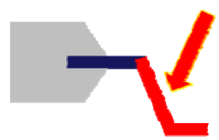
Effects of MFG Exposure on Whisker Growth

- Two sets of accumulated loading cycles completed.
- On non-coated QFPs, the samples exposed to corrosive gases in MFG showed higher whisker density than without MFG exposure.
- The longest whisker was 32 μm on Group1 (without MFG) and 65 μm on Group 2 (with MFG).

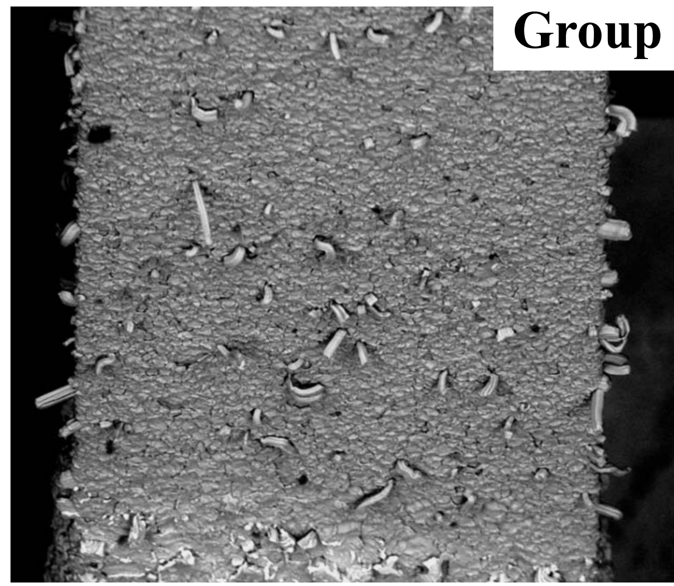


Without MFG exposure

After 2 cycles

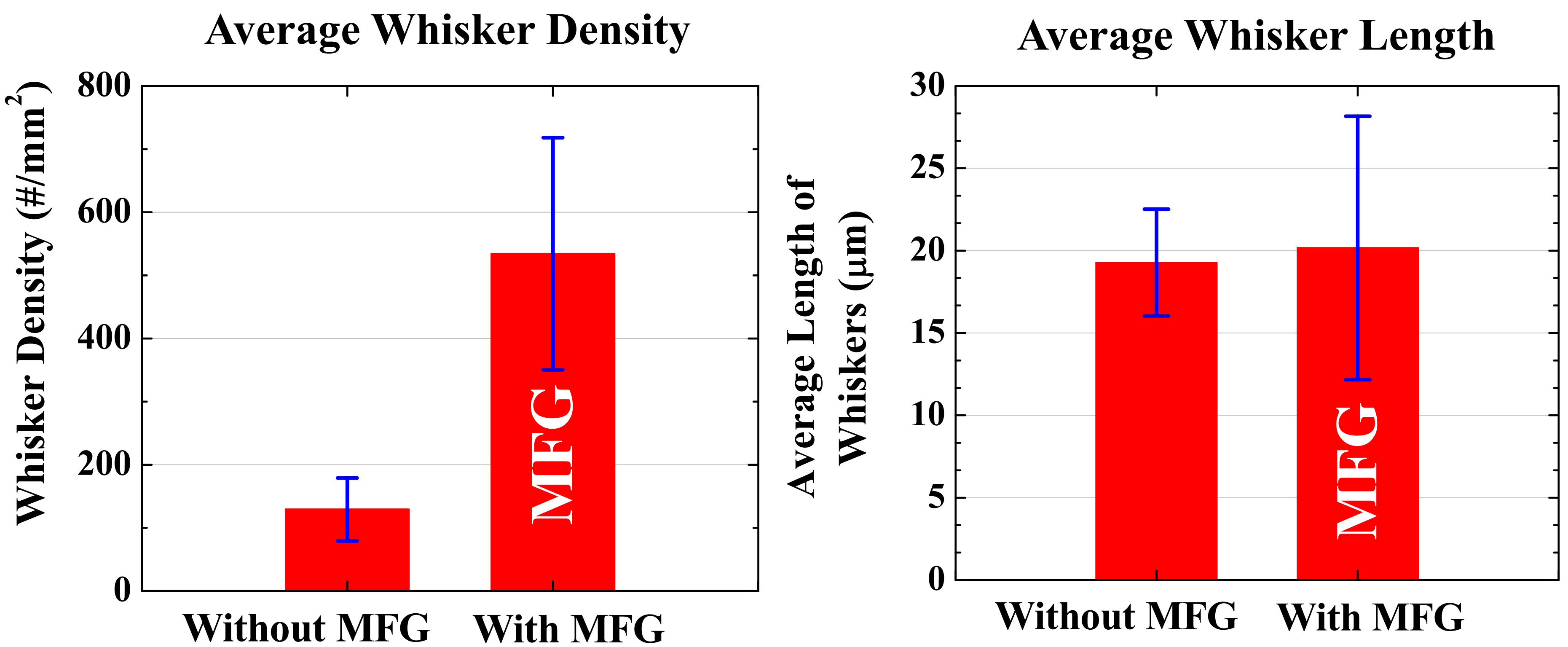


50 μm



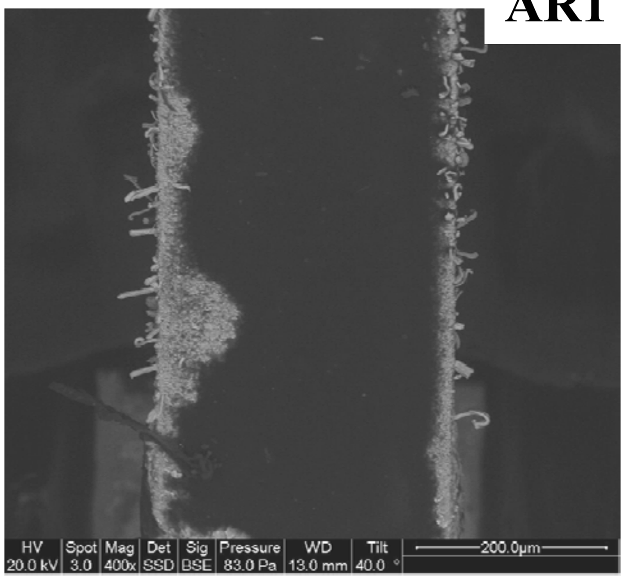
With MFG exposure

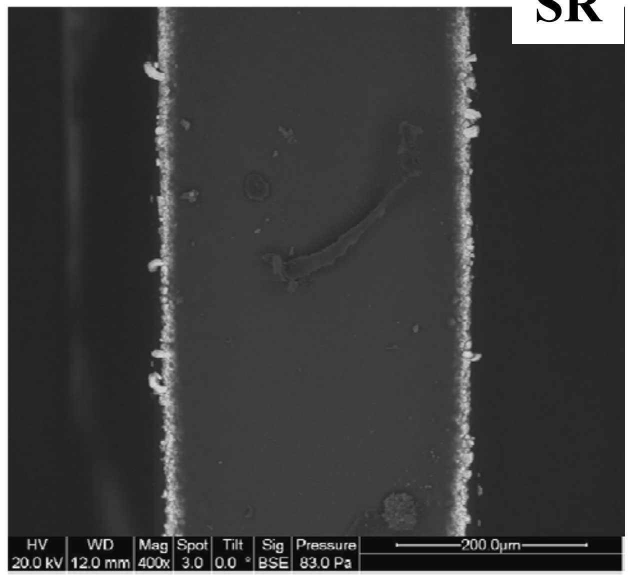
Effects of MFG Exposure on Whisker Growth

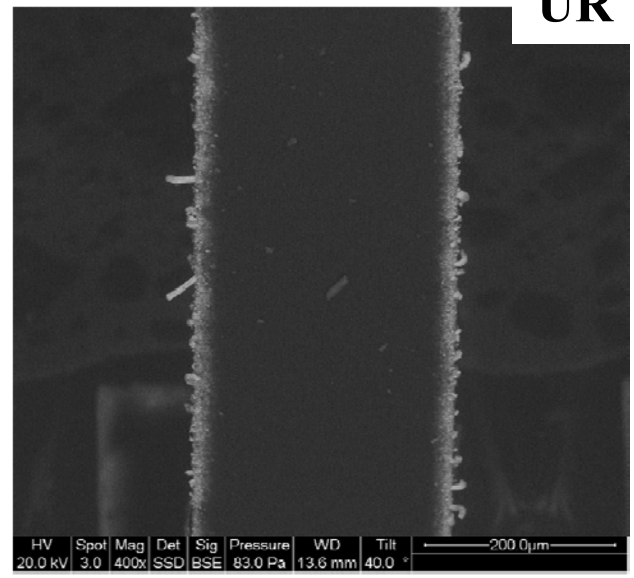


- Statistical results show that the means differ at the 0.05 level of significance in whisker density; however, there is not enough evidence in average whisker length to determine any difference between samples without MFG and with MFG.

Whisker Growth on Conformally Coated QFPs

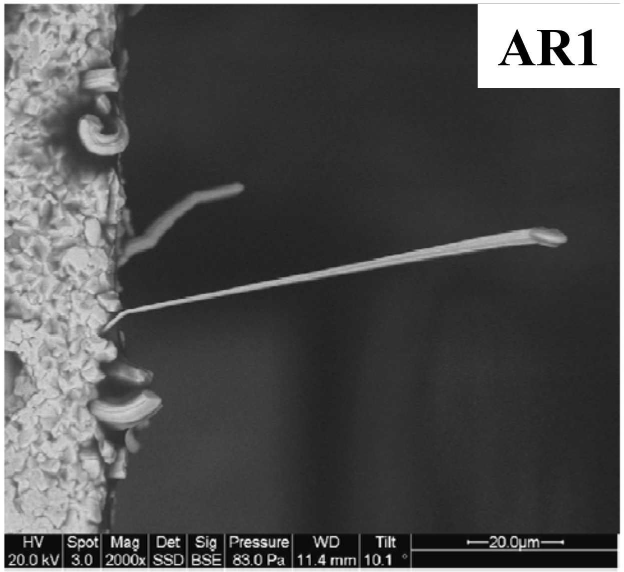


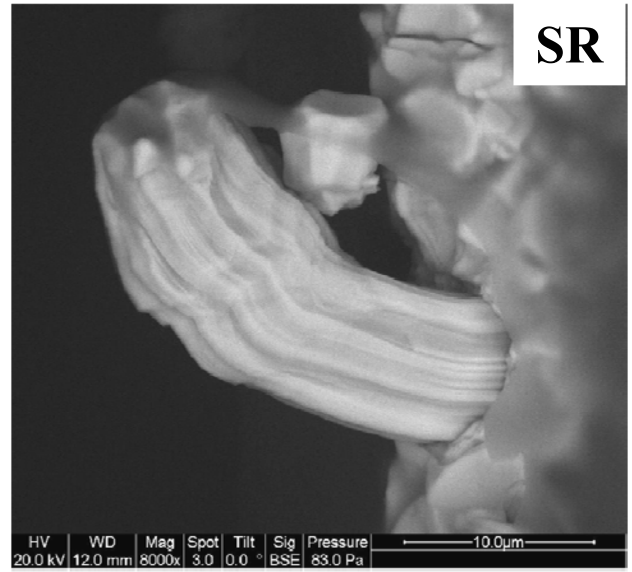


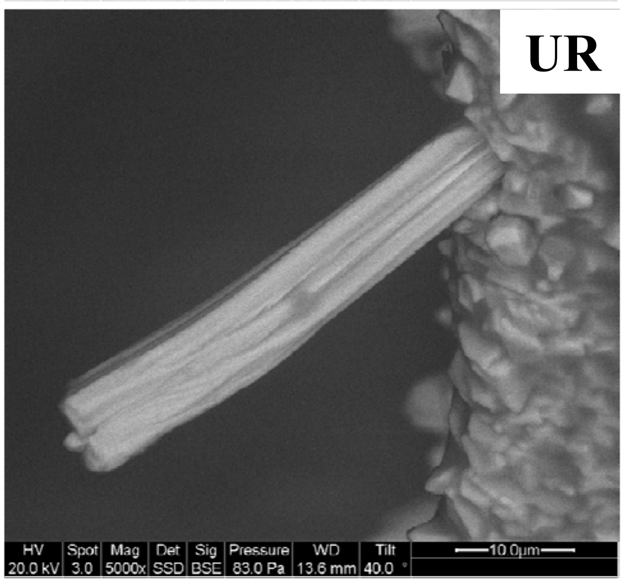


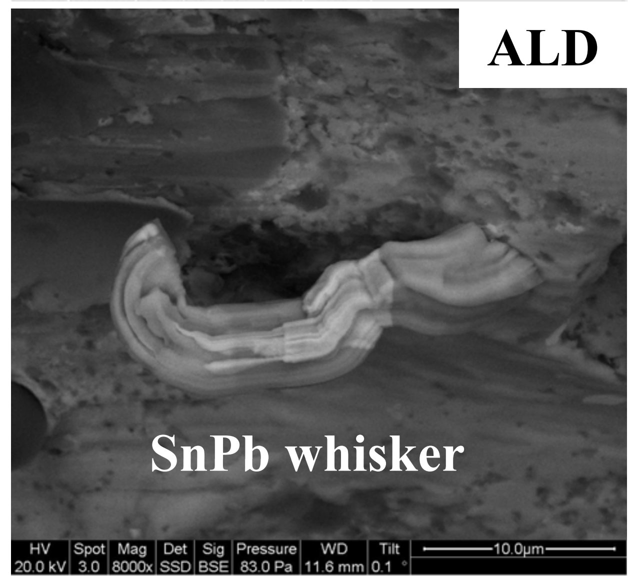
- Whiskers started to grow and penetrate through the AR, SR, UR, and ALD coatings. Most of the whiskers grew on areas with relatively thinner coatings, especially on the sides of the leads.
- Only Parylene C coating did not have whiskers penetrating the coating.

Whisker Growth on Conformally Coated QFPs

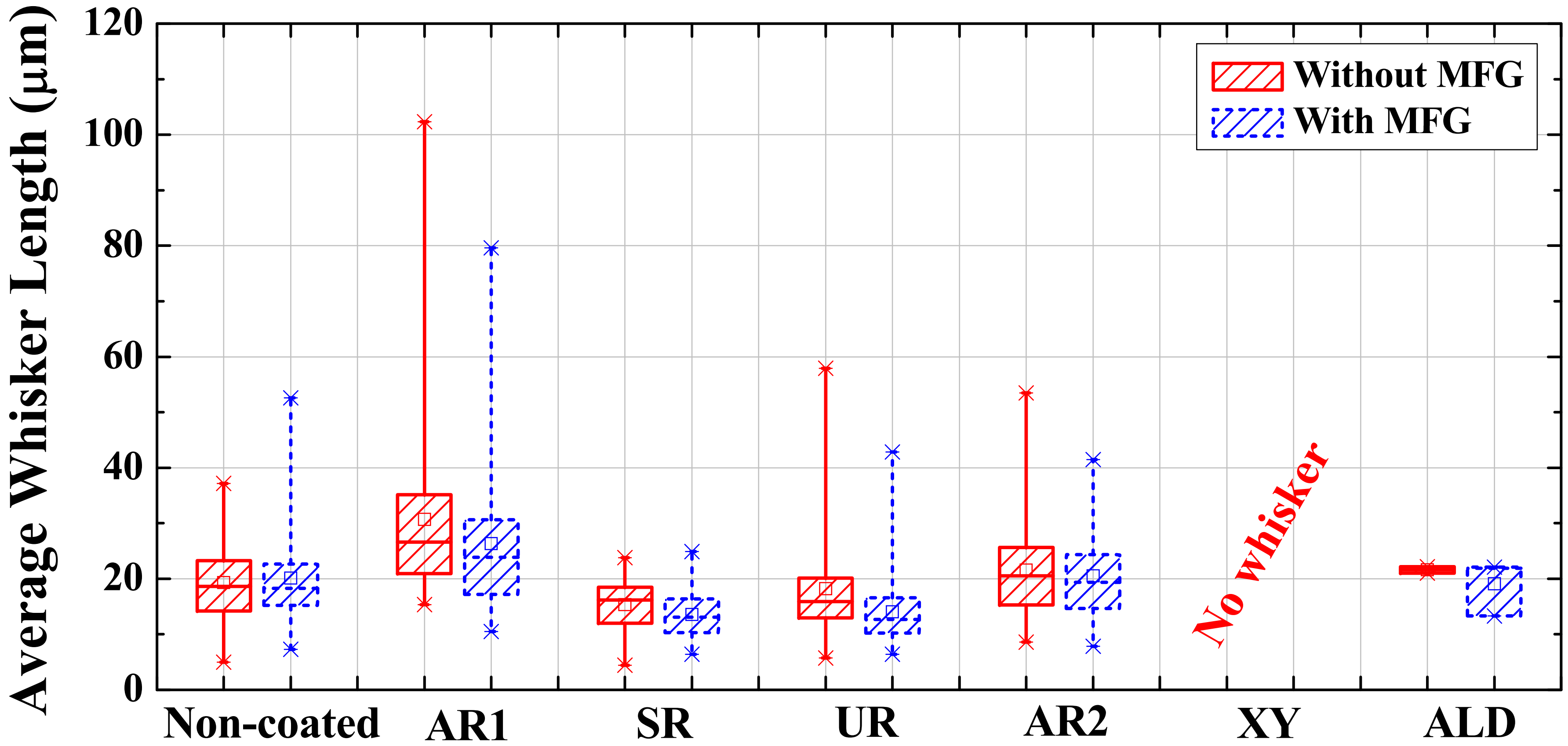








Average Length Whiskers on Conformally Coated QFPs



- The average length of escaped whisker on QFPs with AR1 is longer than the average whisker length on non-coated QFPs.

Summary

- Current practices aim to evaluate coating coverage on flat surfaces and are insufficient for assessing mitigation level provided by spray-on conformal coating on non-level areas.
- Whiskers grew and escaped from the acrylic type 1 and 2, silicone, polyurethane, and ALD coating surface on QFPs after first accumulated loading cycles.
- ALD coating process used in this study was detrimental to glass frits of tested ceramic packages.
- Sn-Pb whiskers grew on ALD coated surfaces of QFPs due to the presence of Pb layer introduced from Pb-containing frit.
- Samples exposed to corrosive gases in MFG showed higher whisker density than without MFG exposure.
- Parylene C coating did not show any whisker penetration.
- Most whiskers grew on areas with relatively thinner coatings or mechanically damaged areas.