On-orbit validation to mitigate Tin whisker growth

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Agenda

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- ExHAM-WHISKER mission objectives
- Overall plan of ExHAM-WHISKER
- Experimental samples
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- Analytical evaluation(Non-coating)
- Analytical evaluation(Conformal coating)
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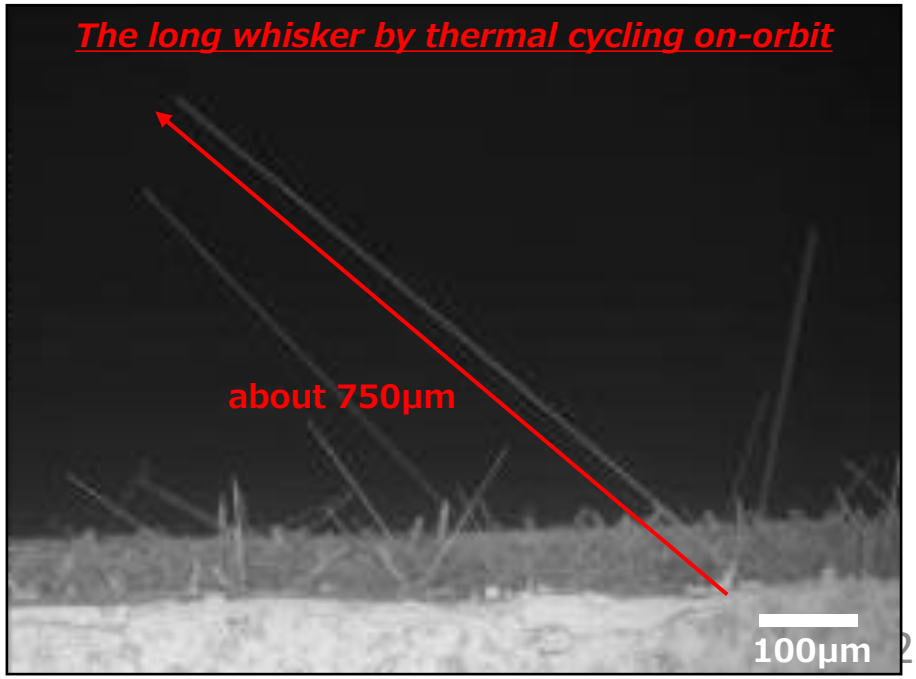
- Future work



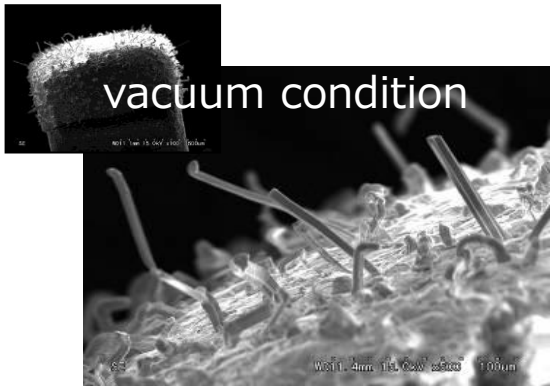
Background

Tin whiskers are microscopic single-crystal metal fibers that grow from pure Tin-plated electrode surfaces that are free from lead solder material. Tin is used extensively in electronic components, and the formation of these whiskers can cause electrical short-circuits and failures. In the absence of lead solder material, the whisker growth is influenced by thermal cycling.

The mission of "**ExHAM-WHISKER**" is to conduct an examination for Tin whiskers in the actual on-orbit environment to validate the effectiveness of countermeasures.

The **past** ground evaluation results

Test condition : Non-coating, air/vacuum(1×10^{-4}Pa) on ground, non-energized, thermal cycling test, -40℃～+85℃, after 500cycle



- Different shapes of Tin whiskers were observed between in air and in vacuum conditions.
- Long and straight Tin whiskers were observed in vacuum condition.

From these results, we decided to conduct an examination for Tin whiskers in the actual on-orbit environment.

ExHAM-WHISKER mission objectives

Mission objective 1)

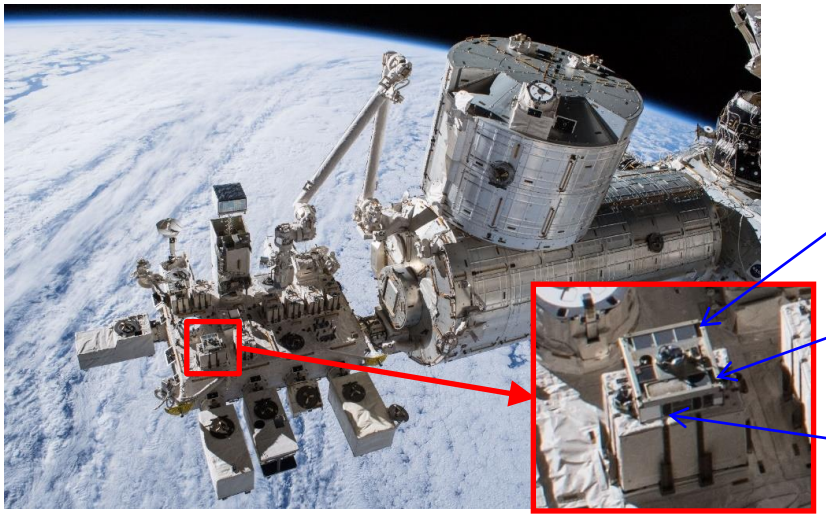
To compare the characteristic of whisker growth both ground in air and on-orbit using the same sample

By comparing with the ground control test in air, we check any difference in whisker growth. We particularly check whether whisker growth saturates on-orbit and ground.

Mission objective 2)

To validate the effectiveness of conformal coatings which may mitigate whisker growth

We validate the occurrence of Tin whisker growth in the conformal coating area after on-orbit exposure and the transformation of the physical properties of each coating agent.



ExHAM-WHISKER sample
(2nd , 3rd and 4th year :3ea)

ExHAM-WHISKER sample
(1st year :1ea)

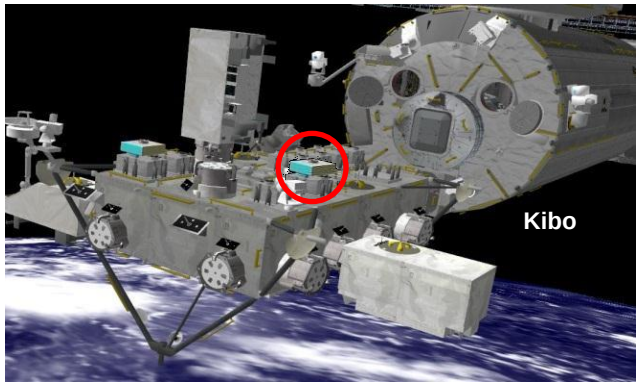
ExHAM-2
(Exposed eXperiment Handrail Attachment Mechanism)

Overall plan of ExHAM-WHISKER

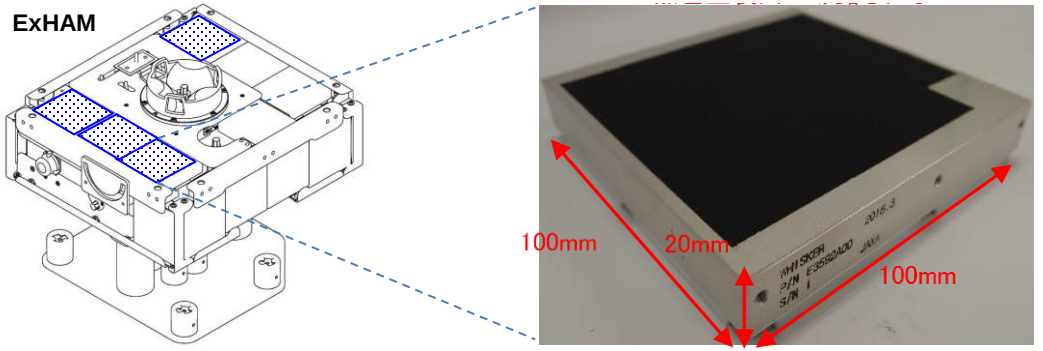
The ExHAM-WHISKER mission has been performed for total 4 years by on-orbit exposure experiments at ExHAM on "Kibo" outboard platform and the corresponding ground control tests for 3 years.

We have been retrieving the samples every year, analyzing and evaluating it.

	2015	2016	2017	2018	2019	2020	2021	2022
Experimental samples	Manufacture		Launch ▲(12/9)	Ground return #1▲	Ground return #2▲	Ground return **#3▲**	Ground return **#4△**	
On-orbit validation			4ea	1st year	2nd year	3rd year	4th year	
Ground control test **(in air)**			3ea	1st year	2nd year	3rd year		
Comparison and summary				Receipt	Receipt	Receipt		
				Analysis/Evaluation				



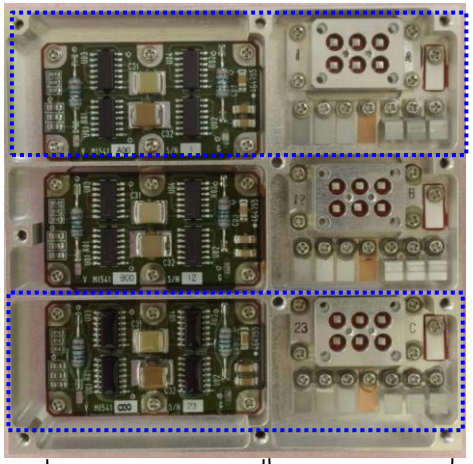
ExHAM(Exposed Experiment Handrail Attachment Mechanism)

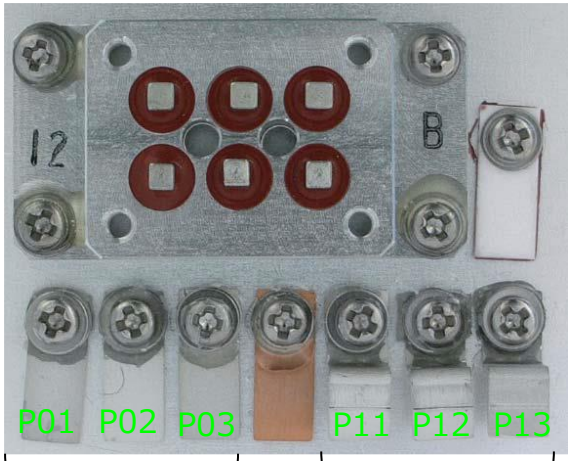


ExHAM-WHISKER Experimental samples

Experimental samples

In order to achieve the ExHAM-WHISKER mission, we prepared PWB and test piece block as experimental samples as follows. Four experimental samples of flight models and three experimental samples of ground control tests have the same configuration.

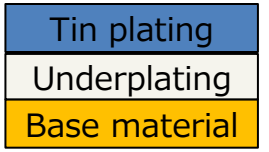




Test piece P01 / Test piece P11
Base :Cu, Underplating :Ni=2μm,
Tin plating=3μm
(Plating **hard** to grow whiskers)

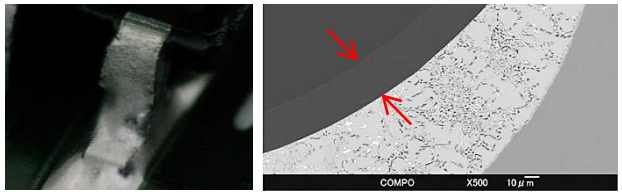
Test piece P02 / Test piece P12
Base :Cu, Underplating :Ni=2μm,
Tin plating=8μm
(Plating **easy** to grow whiskers)

Test piece P03 / Test piece P13
Base :42alloy, Underplating :None,
Tin plating=8μm
(Plating **easy** to grow whiskers)



[Initial analysis data : cross section SEM of SOP IC on PWB]

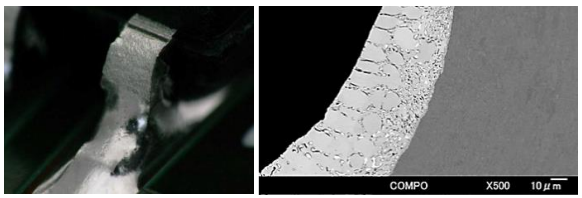
para-xylene coating



Production is vacuum deposition

Thickness: About 25μm (Almost constant thickness)

Non-coating



Urethane coating

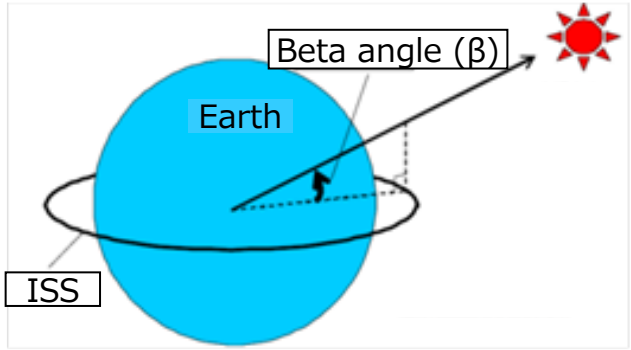
Production applied with brush

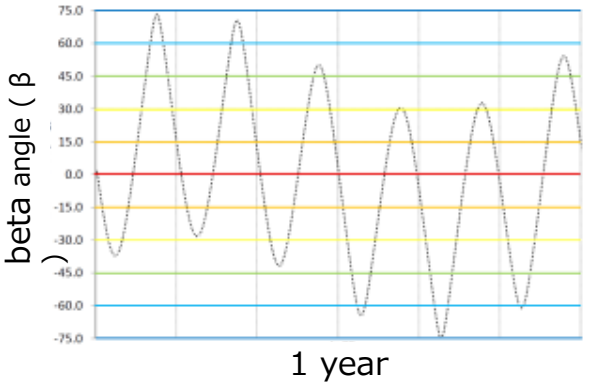
Thickness: About 30μm (Uneven thickness)

Thermal condition of ground control test

For thermal cycling test on ground, thermal analysis was carried out in advance.

Although the actual beta angle changes in analog form, it is set as the test condition (temperature and cycle) for the ground control test by sorting the number of cycles each 15 degrees.





Prediction of β-angle fluctuation for 1 year (Reference)

Temperature prediction each +/- 15 deg of beta angle (Orbit 1 cycle = sunshine and shade)

beta angle	0 deg (+7°～0°, 0°～-7°)	+/- 15 deg (+22°～+7°, -7°～-22°)	+/- 30 deg (+37°～+22°, -22°～-37°)	+/- 45 deg (+52°～+37°, -37°～-52°)	+/- 60 deg (+67°～+52°, -52°～-67°)	+/- 75 deg (+75°～+67°, -67°～-75°)
High temperature	+89℃	+81℃	+65℃	+30℃	+4℃	-19℃
Low temperature	-9℃	-5℃	-14℃	-25℃	-29℃	-32℃
Δt	98℃	86℃	79℃	55℃	33℃	13℃
Days	41	87	103	72	44	18
Cycle	656	1392	1648	1152	704	288

These are calculation values. Actual maximum temperatures on-orbit by thermo label in experimental samples were lower than these calculation values.

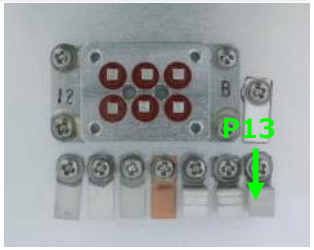
Analytical evaluation (Non-coating)

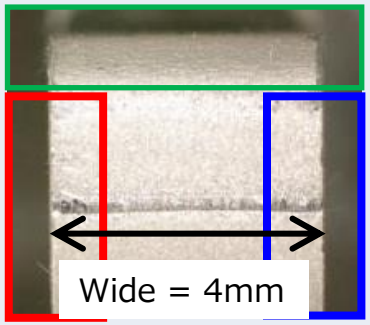
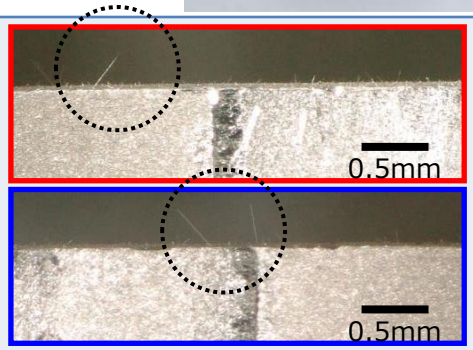
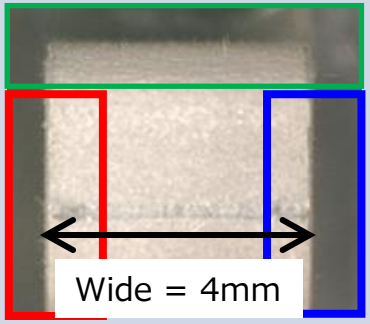
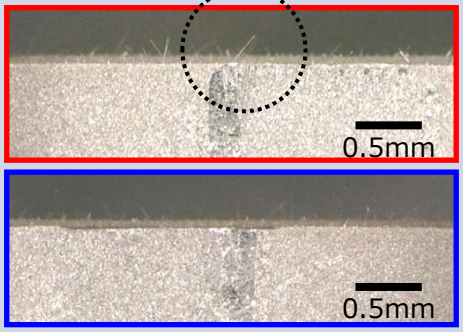
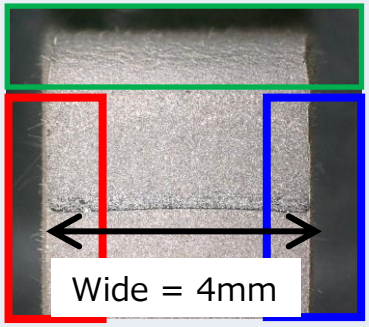
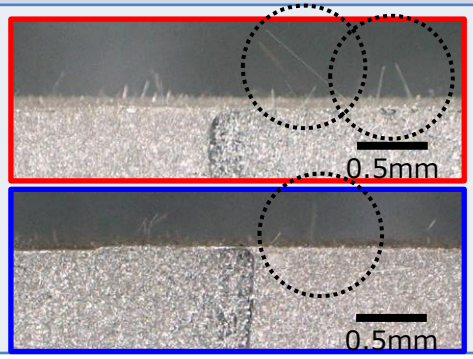
1. Microscope inspection
2. Surface SEM observation
3. Surface EBSD observation
4. Cross-section SEM observation

1. Microscope inspection

whiskers on-orbit

Many whiskers could be seen on the test piece. Whisker length and density were increasing as time proceeds.

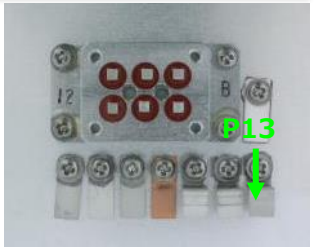


On-orbit 1st year			
On-orbit 2nd year			
On-orbit 3rd year			

2. Surface SEM observation

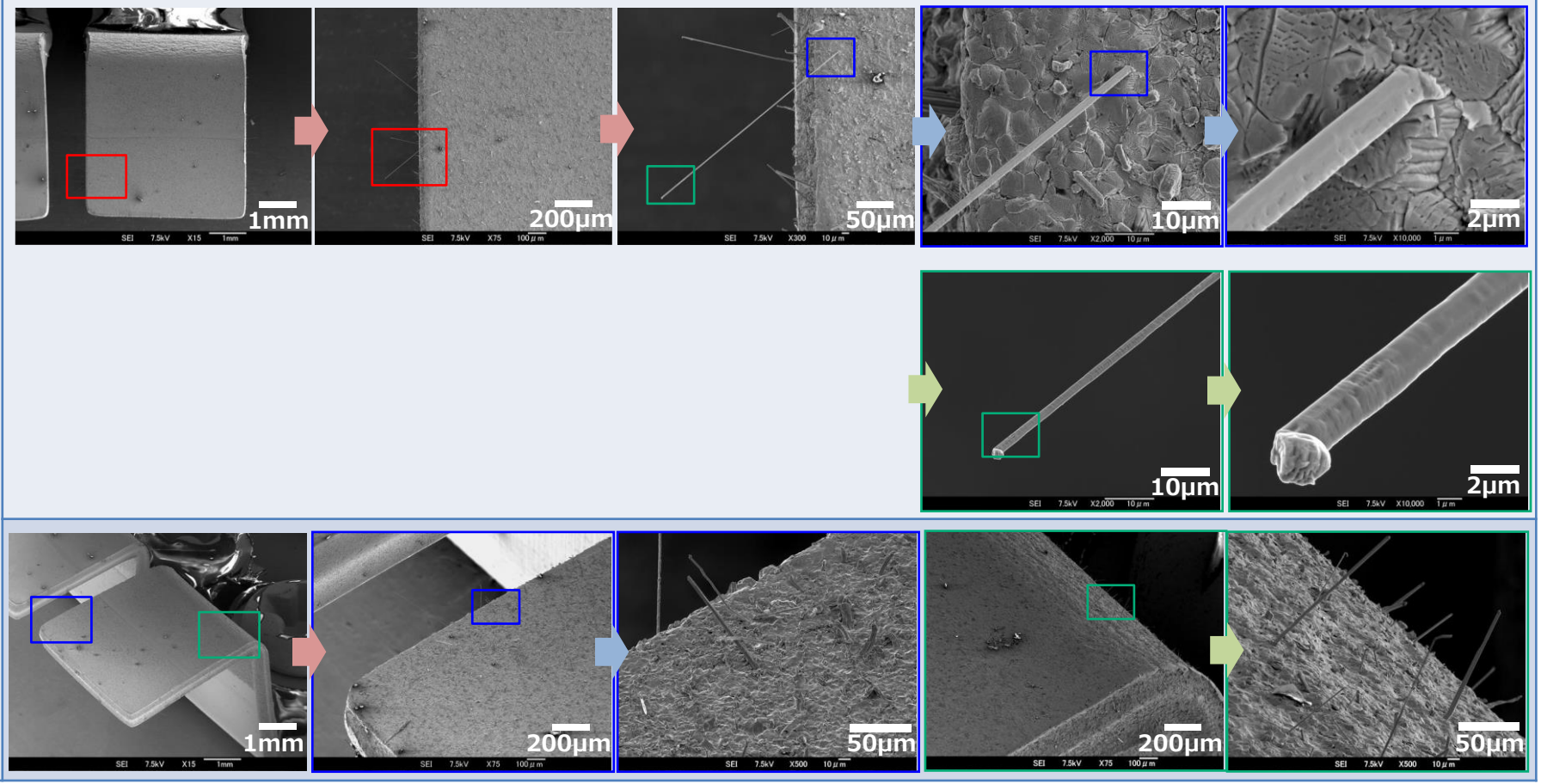
the characteristic of whiskers on-orbit

There were many whiskers, and long, thin and straight whiskers were observed.



On-orbit 1st year

P13

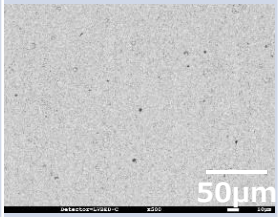
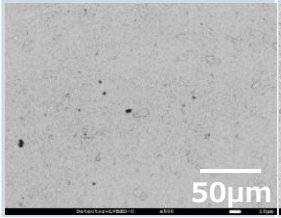
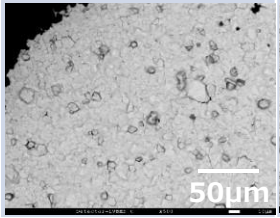
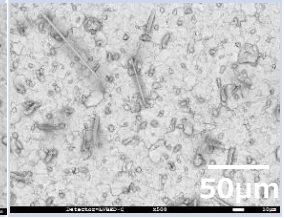
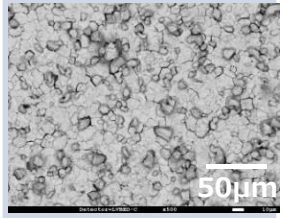
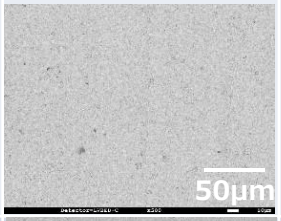
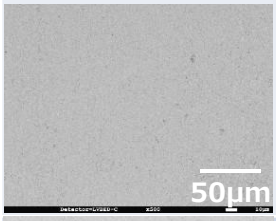
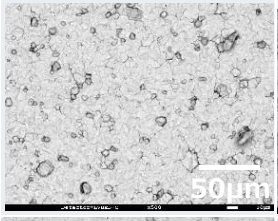
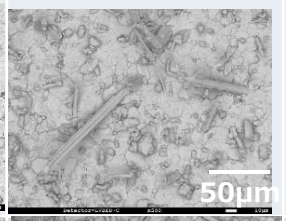
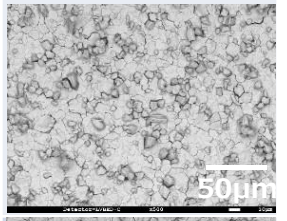
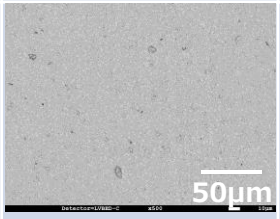
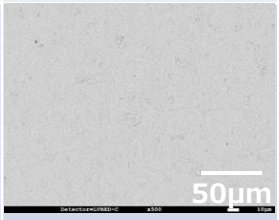
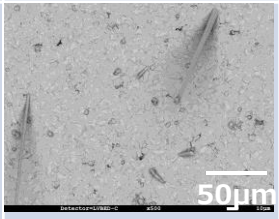
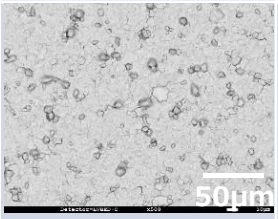
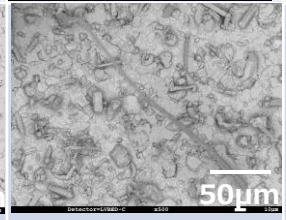
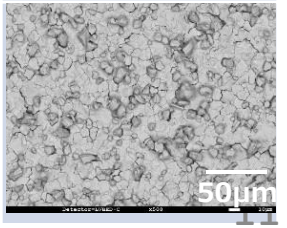


2. Surface SEM observation

the difference of whiskers among Test pieces(P01, P02, P03)

- Test piece P01: There was almost no change.
- Test piece P02, P03: We found many whiskers, and whiskers on-orbit were long. Whereas whiskers on ground were short.

  Surface roughness was increased along with thermal cycling.

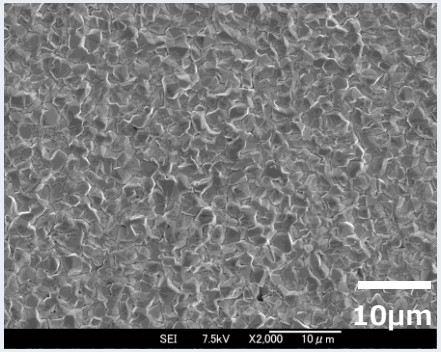
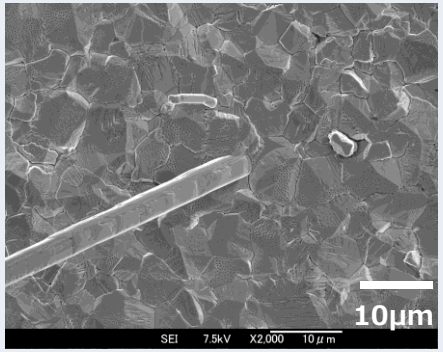
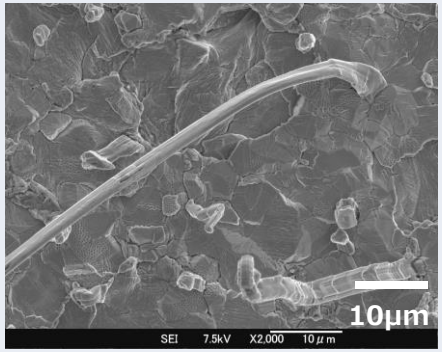
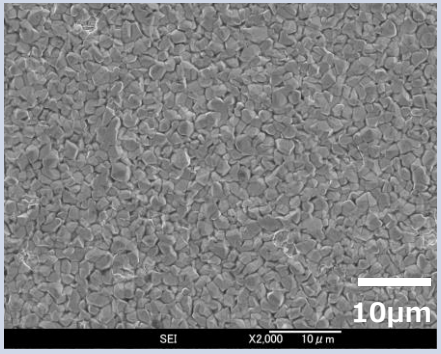
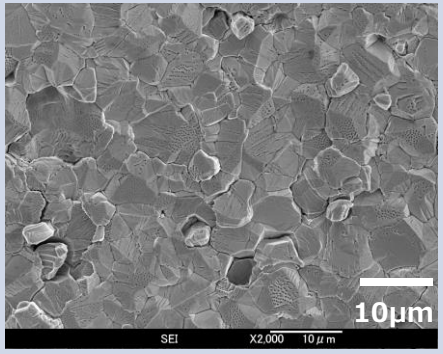
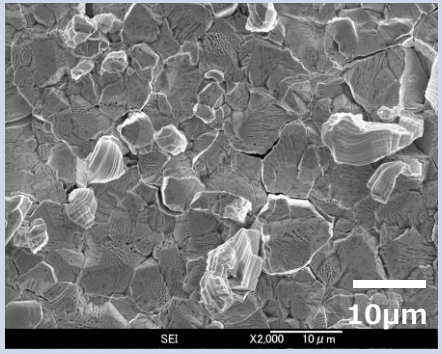
	Test piece(Flat plate) P01		Test piece(Flat plate) P02		Test piece(Flat plate) P03	
	 Base Material :Cu, Underplating :Ni=2μm, Tin plating=3μm (Plating **hard** to grow)		 Base Material :Cu, Underplating :Ni=2μm, Tin plating=8μm (Plating **easy** to grow)		 Base Material :42alloy, Underplating :None, Tin plating=8μm (Plating **easy** to grow)	
	On-orbit	**Ground**	**On-orbit**	**Ground**	**On-orbit**	**Ground**
1st year						
2nd year						
3rd year						

2. Surface SEM observation

the difference of whiskers between on-orbit and ground

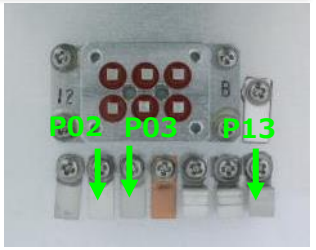
- On-orbit: Tin whiskers were long, thin and straight.
- Ground: Tin whiskers were short, thick and winding.

Tin whiskers on-orbit grew longer, thinner and straighter than Tin whiskers on ground.

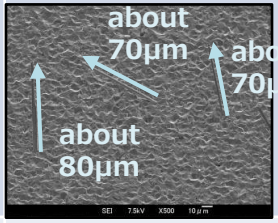
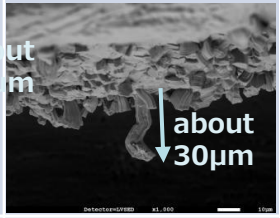
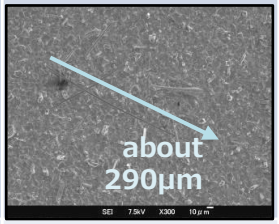
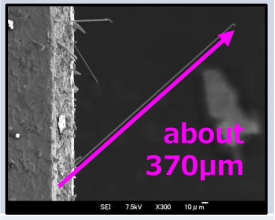
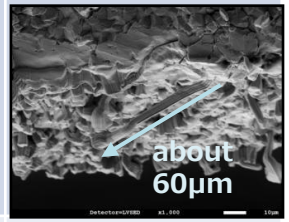
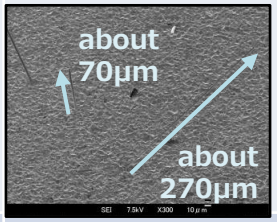
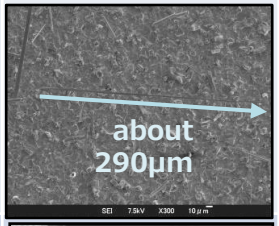
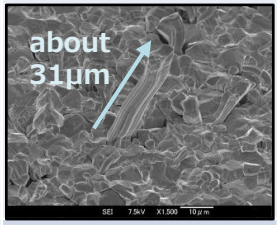
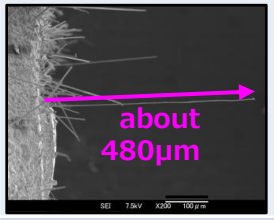
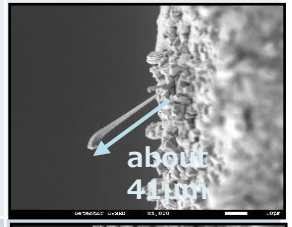
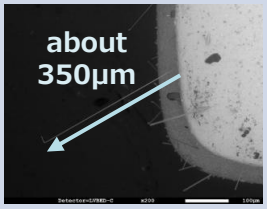
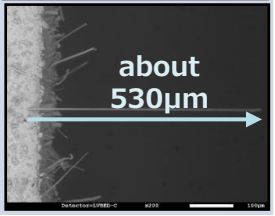
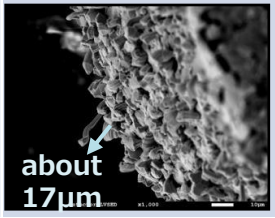
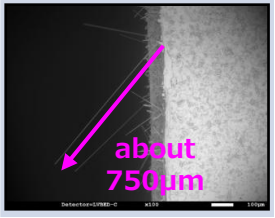
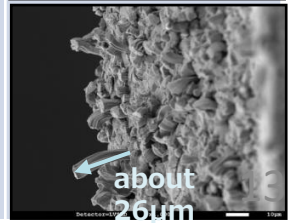
	Test piece(Flat plate) P01	Test piece(Flat plate) P02	Test piece(Flat plate) P03
	 Base Material :Cu, Underplating :Ni=2μm, Tin plating=3μm (Plating hard to grow)	 Base Material :Cu, Underplating :Ni=2μm, Tin plating=8μm (Plating easy to grow)	 Base Material :42alloy, Underplating :None, Tin plating=8μm (Plating easy to grow)
On-orbit 1st year			
Ground 1st year			

2. Surface SEM observation

the saturation of the whisker length



- On-orbit: The maximum length was found in test piece P13 each year. It was observed about 750 μm as the maximum length. The maximum length on-orbit was increasing as time proceeds, not saturated.
- Ground: Tin whiskers grew thicker and shorter, and the length of these whiskers showed a tendency to be saturated.

	Test piece(Flat plate) P02		Test piece(Flat plate) P03		Test piece(Bending plate) P13	
	 Base Material :Cu, Underplating :Ni=2μm, Tin plating=8μm (Plating easy to grow)		 Base Material :42alloy, Underplating :None, Tin plating=8μm (Plating easy to grow)		 Base Material :42alloy, Underplating :None, Tin plating=8μm (Plating easy to grow)	
	On-orbit	**Ground**	**On-orbit**	**Ground**	**On-orbit**	**Ground**
1st year				Not observed		
2nd year		Not observed				
3rd year		Not observed				

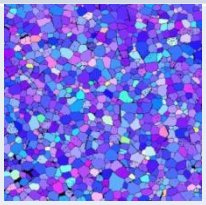
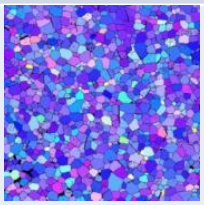
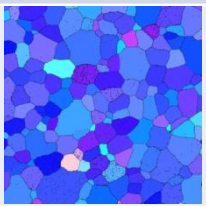
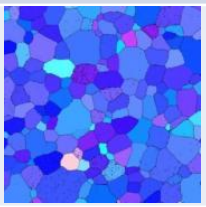
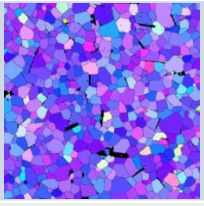
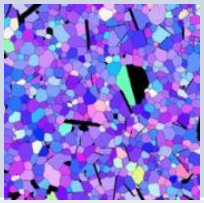
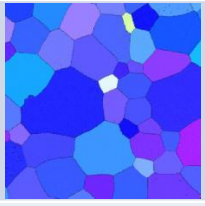
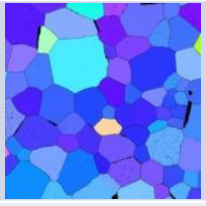
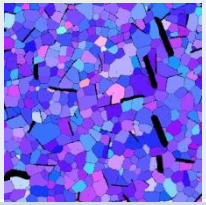
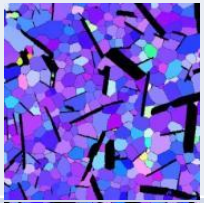
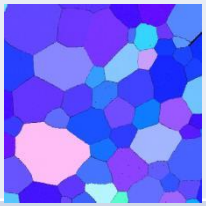
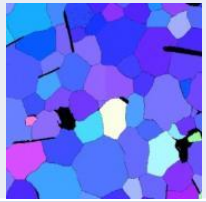
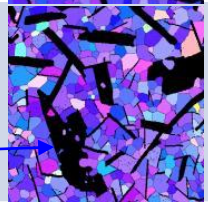
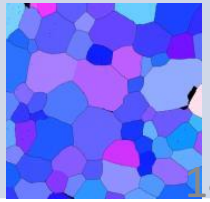
3. Surface EBSD observation

The surface of grain

●Ground: We observed IMC(Intermetallic Compound ; Ni_xSn_x). These IMC were remarkably growing as time proceeds.

The size of grain was increasing both on-orbit and ground, because Tin grains recrystallized to relieve compressive stress by thermal stress of thermal cycling and to be stabilized.

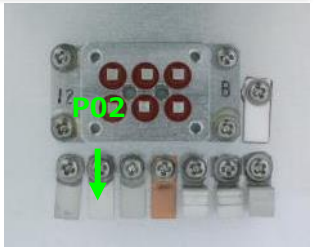
Test piece(Flat plate) P01
 Base Material :Cu, Underplating :Ni=2μm, Tin plating=3μm (Plating hard to grow)
Test piece(Flat plate) P02
 Base Material :Cu, Underplating :Ni=2μm, Tin plating=8μm (Plating easy to grow)

	Test piece1 (Flat plate) P01		Test piece2 (Flat plate) P02	
	On-orbit	Ground	On-orbit	Ground
Initial				
1st year				
2nd year				
3rd year	Under evaluation		Under evaluation	

Black color is IMC.

4. Cross-section SEM observation

the grain boundaries

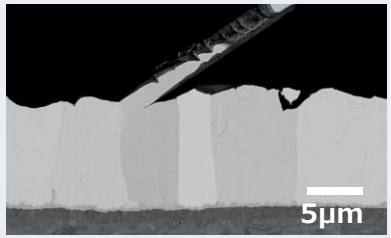
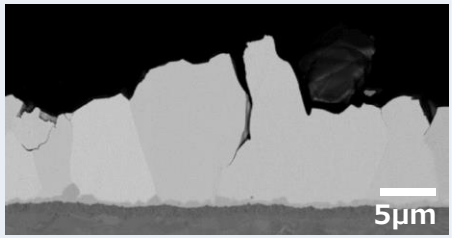
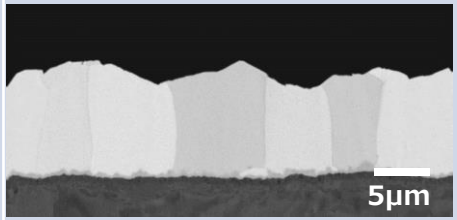
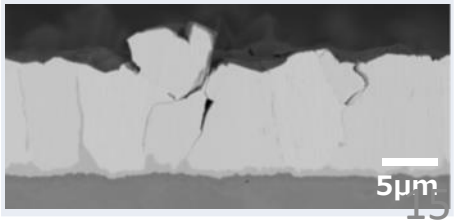


- On-orbit: We could observe the sound contacts at the grain boundaries.
- Ground: Due to the surface of grain boundaries oxidized and IMC; Ni_xSn_x grains, there were not the sound contacts at the grain boundaries.

Tin whisker were formed to relieve compressive stress, so Sn atom diffused in Tin plating.

- On-orbit: The sound contacts at the grain boundary secured the Sn diffusion path toward the whisker.
- Ground: IMC; Ni_xSn_x grains blocked this path and prevented Sn atom Diffusion which caused Tin whisker growth.

Test piece(Flat plate) P02	
	Base Material :Cu, Underplating :Ni=2μm, Tin plating=8μm (Plating easy to grow)

	Test piece2 (Flat plate) P02	
	On-orbit	Ground
1st year		
2nd year		
3rd year	Under evaluation	

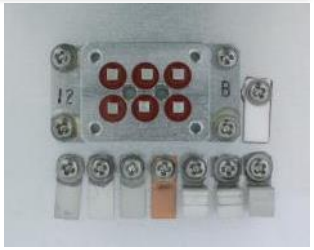
Analytical evaluation (Conformal coating : Para-xylene, Urethane)

1. Microscope inspection
2. Surface SEM observation
3. Cross-section SEM observation
4. Nano indenter

1. Microscope inspection

The changing of the samples of conformal coating

- Para-xylene coating: There was no changed both on-orbit and ground.
- Urethane coating: There was changed to yellow on only ground.



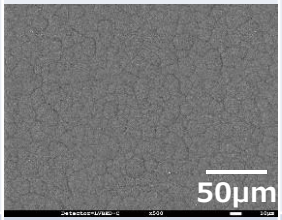
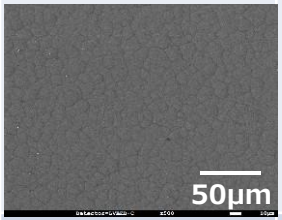
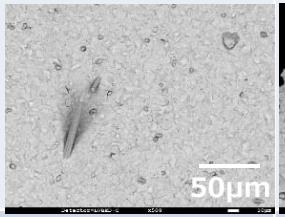
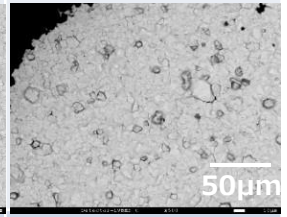
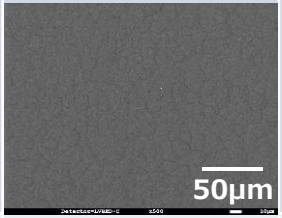
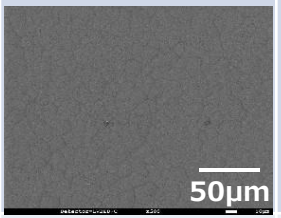
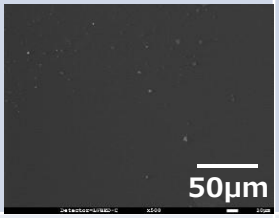
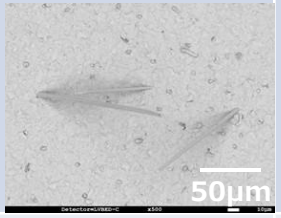
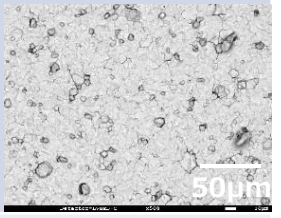
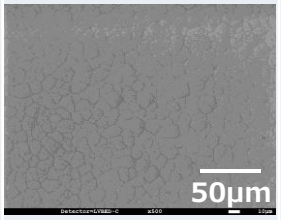
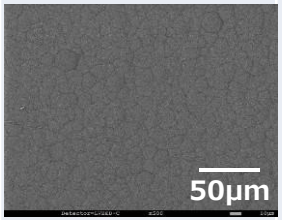
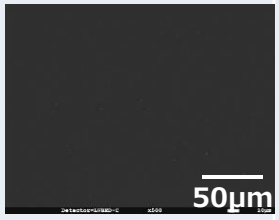
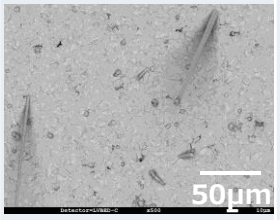
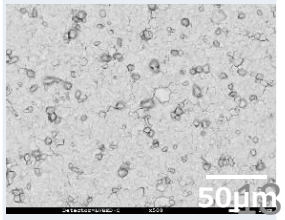
It is assumed that Urethan coating was weak under air condition and there were oxidation and moisture absorption during thermal cycling on ground.

	Para-xylene coating		Urethane coating	
	On-orbit	**Ground**	**On-orbit**	**Ground**
Initial				
1st year				
2nd year				
3rd year				

2. Surface SEM observation

the effectiveness of conformal coating

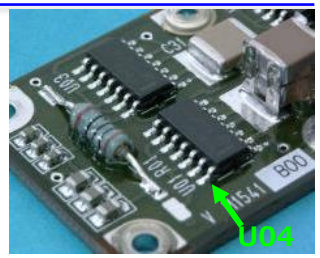
- Para-xylene coating: There was no whisker growth both on–orbit and ground.
- Urethane coating: There was no whisker growth in the thick urethane coating both on–orbit and ground.
- No coating: There were many whiskers both cases.

	Para-xylene coating		Urethane coating		Non-coating	
	On-orbit	Ground	On-orbit	Ground	On-orbit	Ground
1st year						
2nd year						
3rd year						

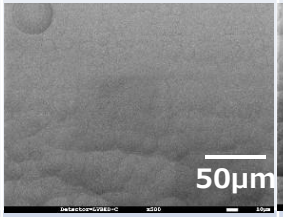
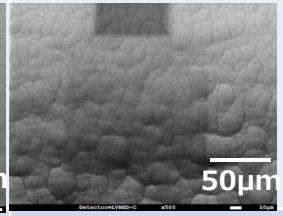
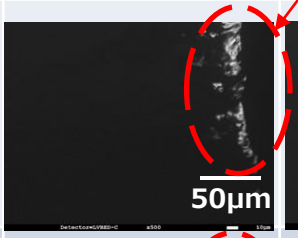
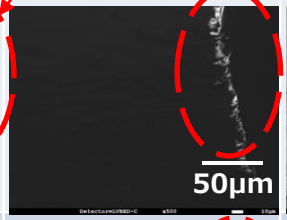
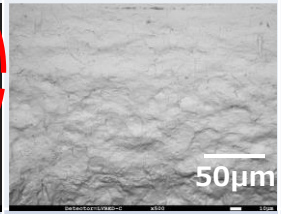
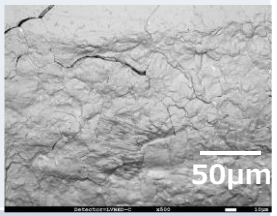
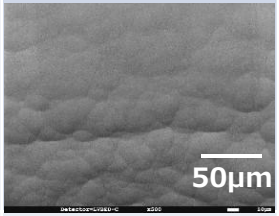
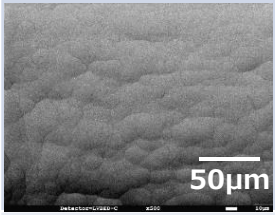
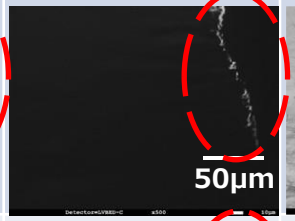
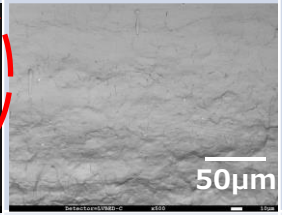
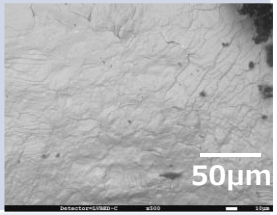
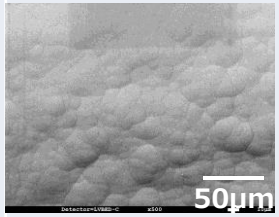
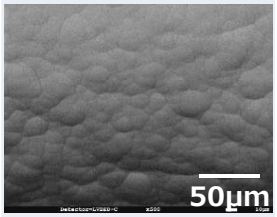
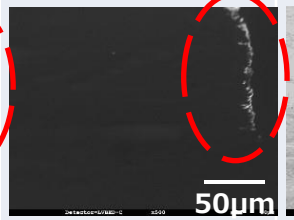
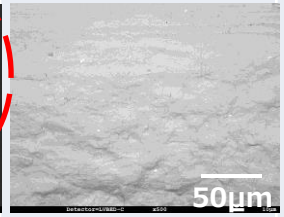
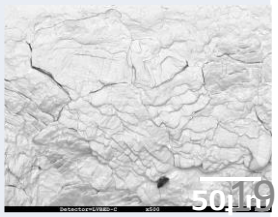
2. Surface SEM observation

the effectiveness of conformal coating

- Para-xylene coating: There was no whisker growth both on–orbit and ground.
- Urethane coating: There was no whisker growth in the thick urethane coating both on–orbit and ground. However, we observed thin coated or uncoated area.



Thin coated or uncoated area
(Exposure of lead parts)

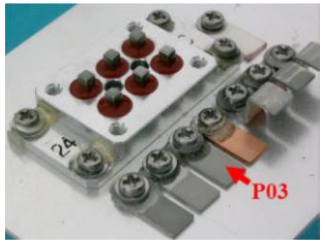
	Para-xylene coating		Urethane coating		Non-coating	
	On-orbit	Ground	On-orbit	Ground	On-orbit	Ground
1st year						
2nd year						
3rd year						

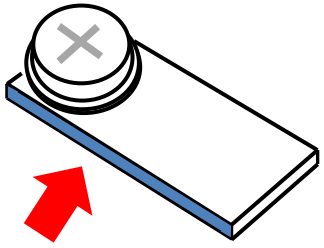
2. Surface SEM observation

the effectiveness of conformal coating

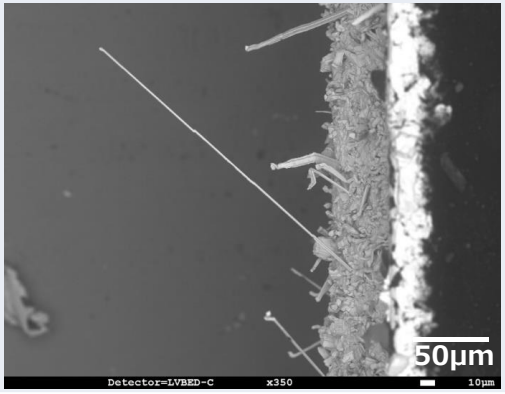
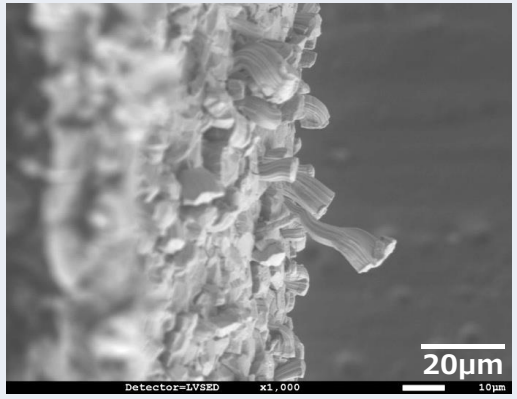
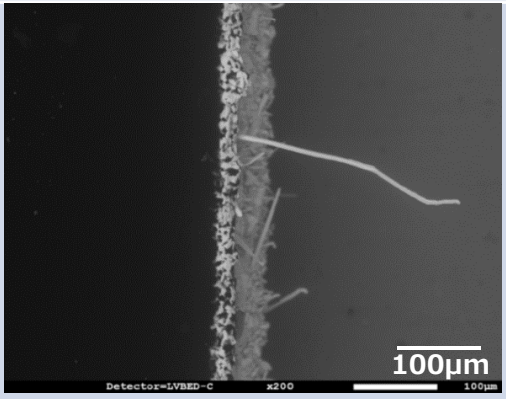
●Urethane coating:

Tin whisker growth was not observed in the thick urethane coating, however, there were uncoated areas on the edge, and Tin whisker growth was observed in uncoated area both on-orbit and ground.





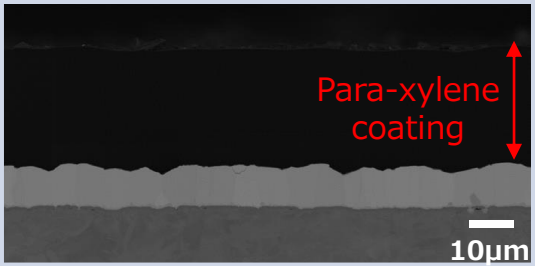
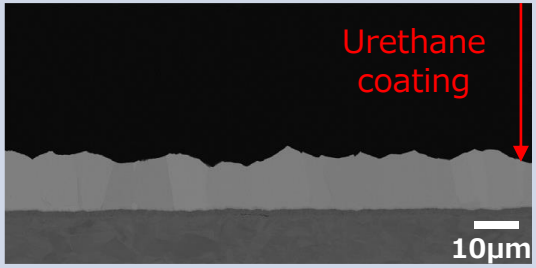
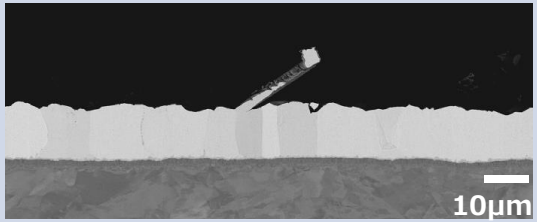
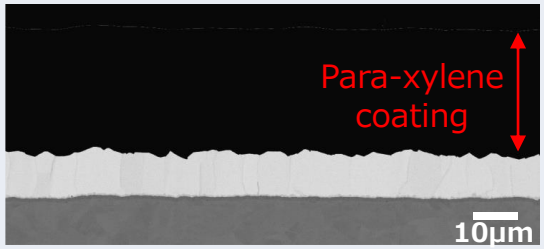
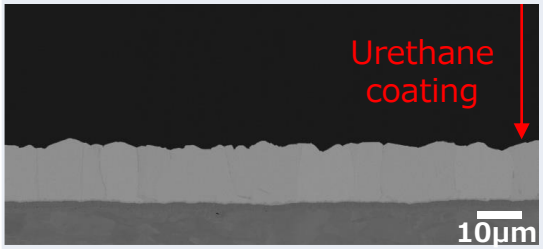
Uncoated area on the age

	Urethane coating	
	On-orbit	Ground
2nd year		
3rd year		

3. Cross-section SEM observation

the effectiveness of conformal coating

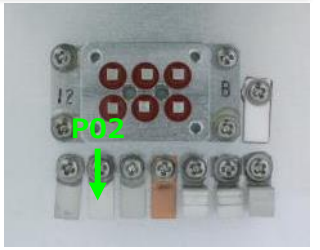
It was observed that para-xylene coating and urethane coating prevent whisker growth. There were no whiskers under each coating.

	Para-xylene coating	Urethane coating	Non-coating
On-orbit 1st year			
On-orbit 2nd year			
On-orbit 3rd year	Under evaluation	Under evaluation	Under evaluation

3. Cross-section SEM observation

the surface of Tin plating under coating

- Urethane coating: The surface of Tin plating under coating became rougher.
- Para-xylene coating: The surface of Tin plating under coating was almost no changed.



It can be seen that Para-xylene coating is better than Urethane coating to mitigate whisker growth.

	Para-xylene coating	Urethane coating	Non-coating
Ground 1st year	Para-xylene coating, 10μm	Urethane coating, 10μm	10μm
Ground 2nd year	Para-xylene coating, 10μm	Urethane coating, 10μm	10μm
Ground 3rd year	Almost no change; Para-xylene coating, 10μm	rougher; Urethane coating, 10μm	Rougher and growth of whisker, 10μm

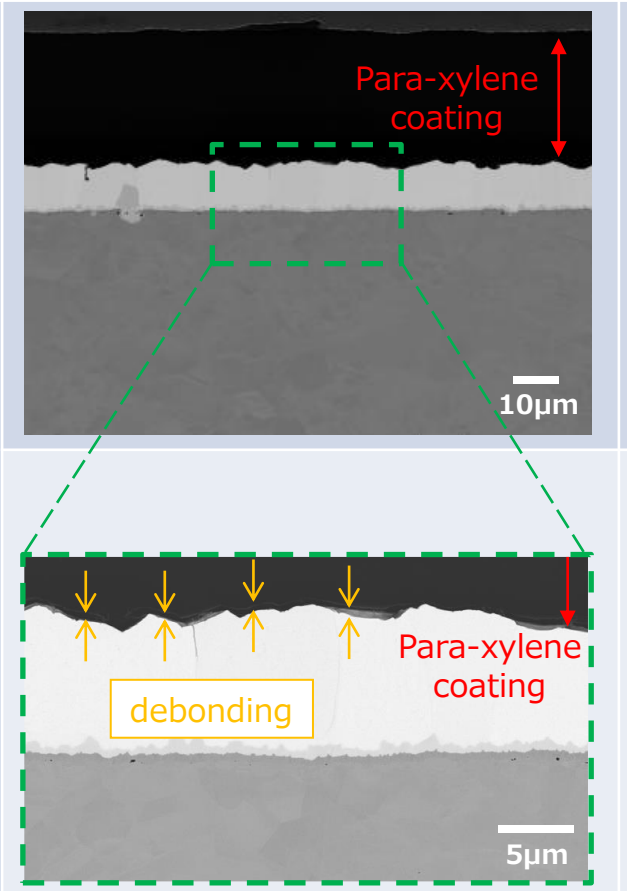
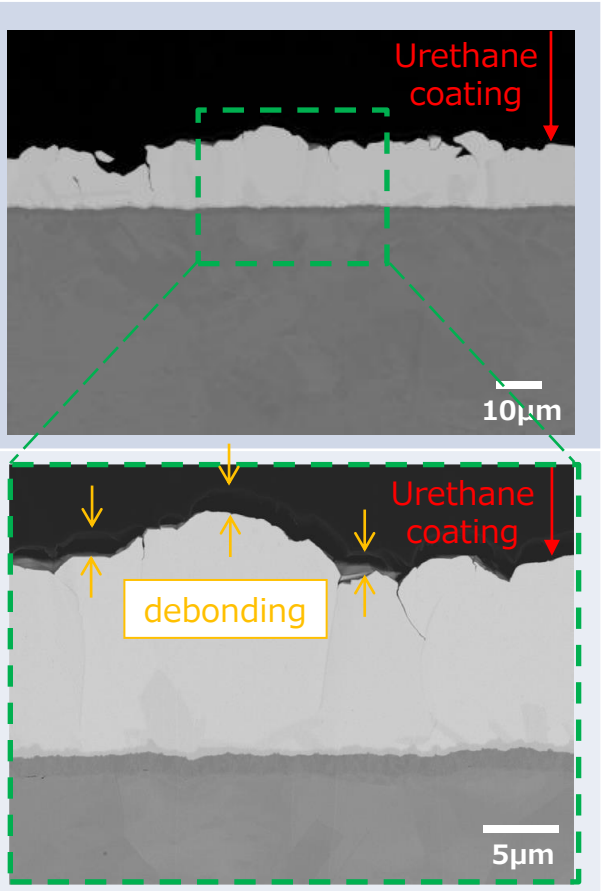
3. Cross-section SEM observation

the surface of Tin plating under coating

Debonding of coating were observed in part of test piece block in para-xylene coating and urethane coating on ground 3rd year.

We suppose that debonding were happened due to roughness of Tin plating in Urethane coating.

We need to confirm degradation of each conformal coating on-orbit 3rd year and 4th year.

	Para-xylene coating	Urethane coating
Ground 3rd year		

4. Nano Indenter

the hardness and Young's module of Para-xylene coating

In the past, we confirmed that high degree of hardness and high young's module showed effectiveness of mitigating whisker growth.

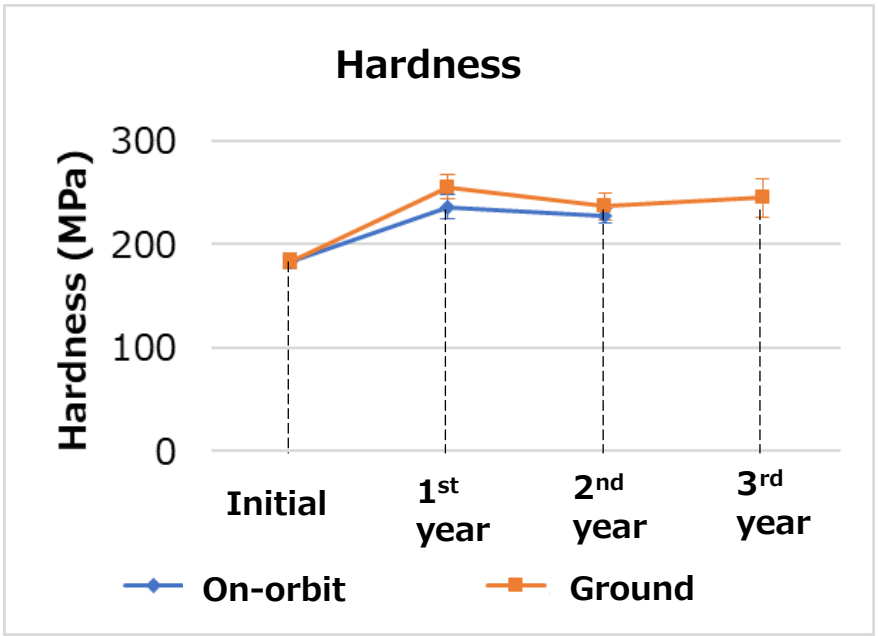
Para-xylene coating had about one hundred times hardness and Young's module of Urethane coating. Due to this, Para-xylene coating could prevent whisker growth.

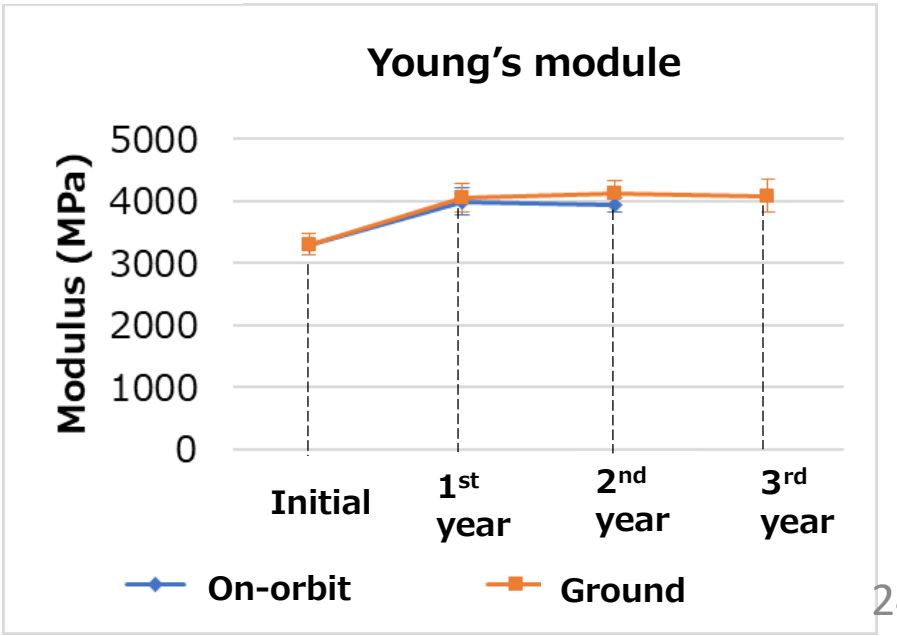
Flat Plate
(Al_2O_3 (A493))

As shown in the following figures, Hardness and Young's module were increasing from initial to 1st year both on-orbit and ground. But they were not almost changed from 1st year to 2nd year.

It is thought that characteristic of coating changed from initial, but it could prevent whisker growth.

Para-xylene coating





Summary

The summary is as follows.

Mission objective 1)

To compare whisker growth both ground in air and on-orbit using the same sample

- Ground : The tendency to slow down of the Tin whisker growth was confirmed.
- On-orbit : The length of Tin whiskers were longer than expected, and not saturated.

→ We will validate whether the growth of Tin whiskers on-orbit is saturated from observation data of the next 4th year sample.

Mission objective 2)

To validate the effectiveness of conformal coatings which may mitigate whisker growth

- Para-xylene coating : There was no growth of Tin whiskers on ground and on-orbit, and the suppressing effect was confirmed.
- Urethane coating : There was no growth of Tin whiskers in the thick coating area, and partial whisker suppression effect was obtained.

Future work

We will validate as follows.

Characteristic of whisker growth

- Whether the growth of Tin whiskers on-orbit is saturated from observation data of the next 4th year sample.
- Tendency of the maximum length and the density of Tin whiskers both on-orbit and ground
- Mechanism of Tin whisker growth on-orbit

Effectiveness of conformal coating

- Whether the growth of Tin whiskers is found on thin urethane coated area
- Tendency of degradation of each conformal coating
- Mechanism of mitigating Tin whiskers by conformal coating

Finally, we will provide guideline of lead-free parts application standard incorporating suppression measures against Tin whiskers.

Please let us exchange information about Tin whisker with you in the future.

Thank you for your attention !