IPC Symposium on Tin Whiskers

Study of tin whisker inhibiting systems Controlling the copper substrate roughness and controlling the tin deposit crystal structure

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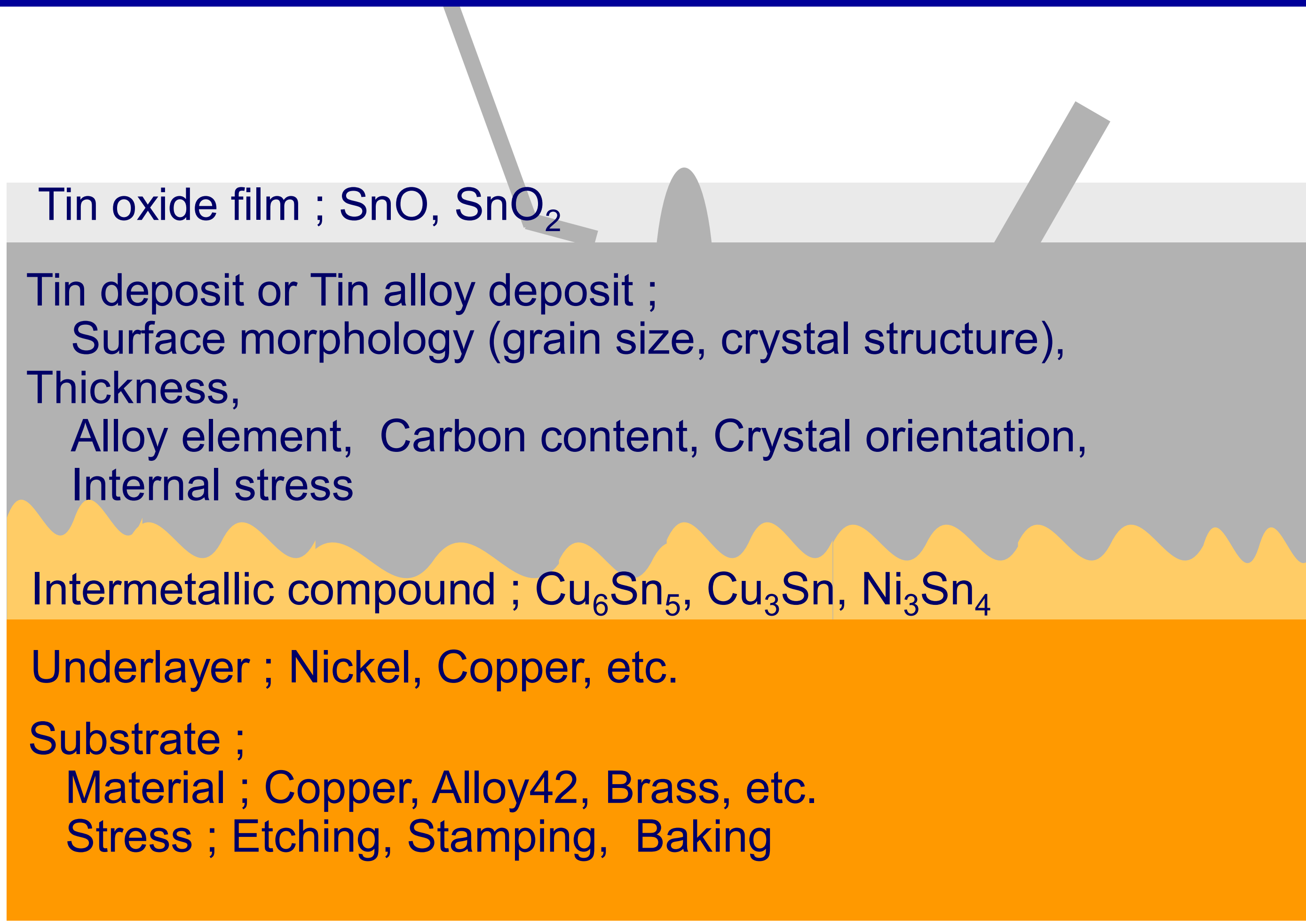
- The factors of tin whisker formation
- Mechanism of tin whisker formation at ambient
- Checking the effect of copper surface roughness in tin whisker formation
- Checking the effect of tin deposit crystal structure in tin whisker formation
- Summary

Background

- Pure tin and tin based alloys plating for alternative of tin-lead finish is being used on the majority of electronic components.
- Tin whisker of tin and tin based alloy deposits are commonly known to cause the short circuits in electronic components.
- In the case of tin finish on copper and copper based alloys, the major cause of tin whisker formation is compressive stress which is increased by irregular growth of copper-tin intermetallic compound (IMC) at ambient conditions.
- It is known that tin whiskers are formed easily on the plated tin deposit, and are prevented on the tin-lead deposit. The tin deposit and tin-lead deposit are different in the crystal structure. So, we had a hypothesis of the crystal structure impacting tin whiskers. Then we checked tin whisker on tin deposit controlling the equiaxed crystal structure similar to tin-lead deposits.

Factors of tin whisker formation



After treatment ; Baking, Reflow

Environment ; Temperature, Humidity, Thermal cycle, Mechanical stress

Factors of tin whisker formation and whisker evaluation methods

Tin deposit

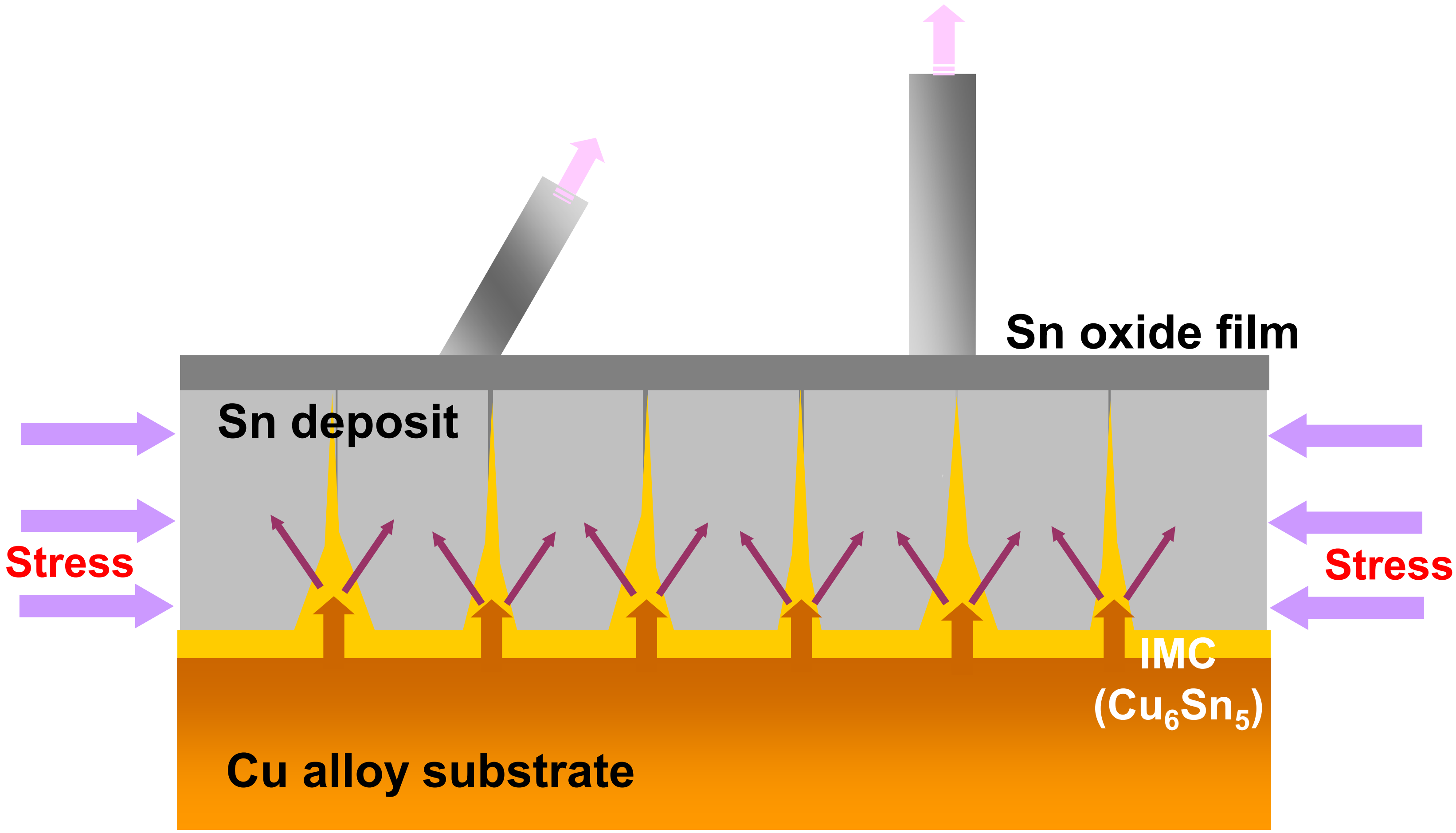
	Internal stress (compressive stress)			External stress
Environment	**Room temperature**	**High temperature /High humidity**	**Thermal cycling**	**Indentation test**
Test conditions	**30℃,60%RH 4,000 hrs.**	**55℃,85%RH 4,000 hrs.**	**-55℃ to 85℃ 1,500cycles**	**(ex.) Load:2N Dwell time:120hrs.**
Factors	**Growth of irregular IMC**	**Oxidation /Corrosion**	**Thermal expansion mismatch**	**External applied force**

This condition is most serious condition

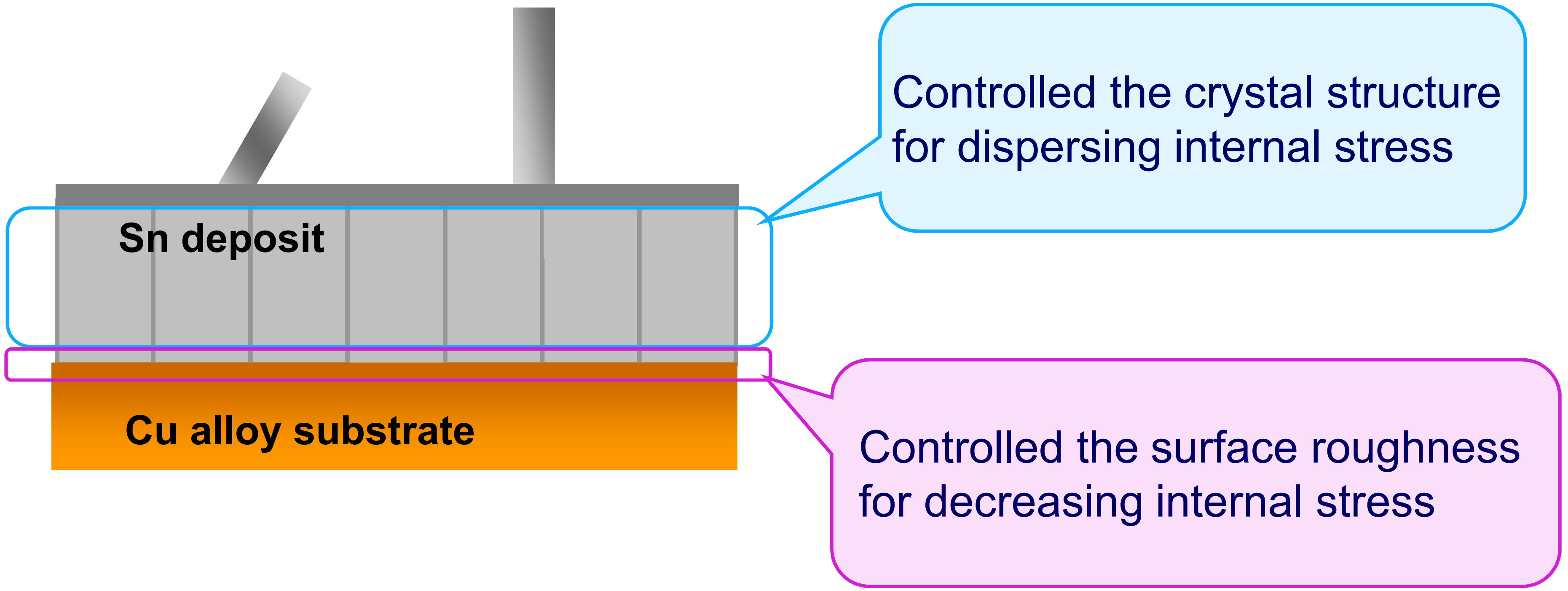
Tin whisker

※ JESD201(JEDEC), RC-5241(JEITA)

The mechanism of tin whisker formation at ambient that is the most serious condition



Approach to reduce tin whisker formation



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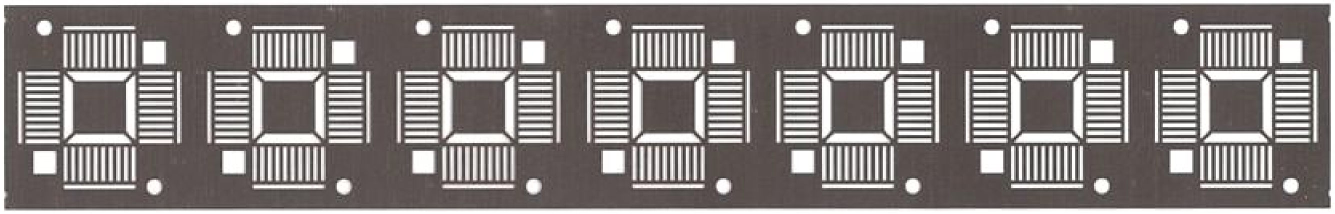
Study of Copper surface morphology vs. Tin whisker formation

Experiment

Test vehicle

- CDA19400 (Cu-2.3Fe-0.03P-0.12Zn) leadframe
  (Original leadframe)



Tin plating

- Plating bath : MSA matte tin plating bath
- Cathode current density : 10A/dm^2
- Thickness ; 3µm (for evaluating whisker in the short term)
  10µm (typical thickness for leadframe)

The copper surface control method

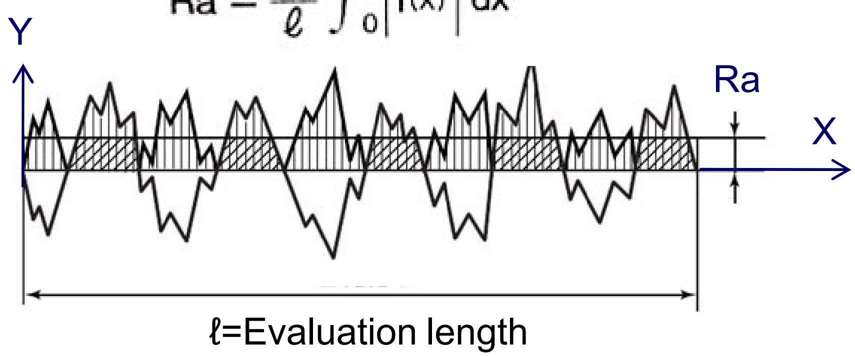
Etching

- Etchant : Various etchants were used for forming surface roughness on copper substrate.
- Measurement

  Surface roughness was analyzed by laser microscope

  Parameter : Ra(μm) arithmetic average of absolute values

$$Ra = \frac{1}{\ell}\int_0^{\ell}\left|f(x)\right|dx$$



Ra ; From the direction of the average line of the roughness curve of a sampled standard length, plot the direction of the average line of the sampled section on the X axis and the direction of the vertical magnification on the Y axis, and express the roughness curve using the equation y=f(x). The roughness value is then expressed in micrometers (μm) as the value determined from the left expression.

The evaluation method of tin whisker formation

Whisker test

- Storage condition : 30°C / 60%RH
- Storage time : 1,000hours (for 3μm thickness tin deposit)
  4,000hours (for 10μm thickness tin deposit)
- Parameter : Maximum whisker length
  Whisker density
- Definition of whisker
  Aspect ratio (length/diameter); more than 2
  Whisker length; more than 10μm
- Measurement method of whisker length; JEITA ET-7410
  The straight line distance from the point of emergence of the whisker to the most distant point on the whisker.

Outline of the evaluation

Plating process (Common process of tin plating)

Cleaning → Acid dipping → Etching → Pre-dipping → Tin plating → Neutral-ization → Drying

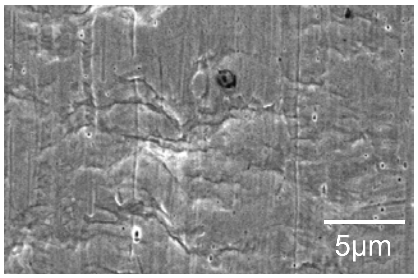
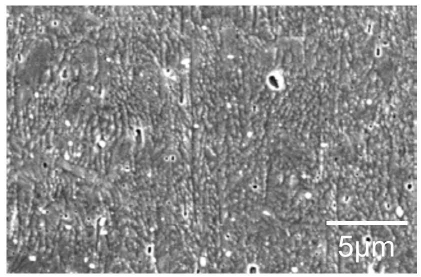
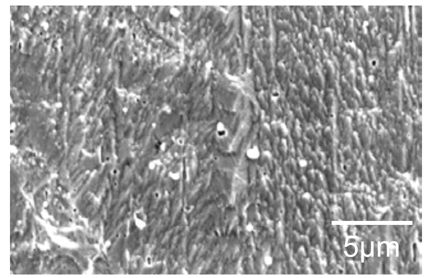
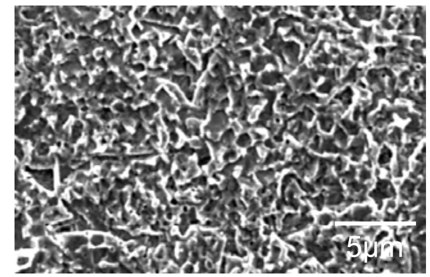
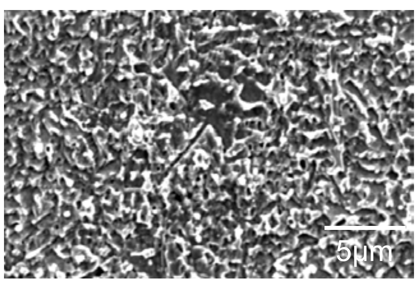
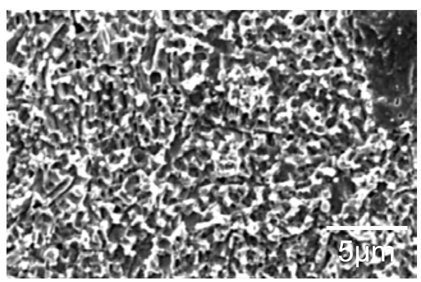
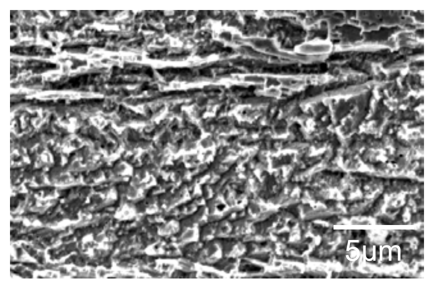
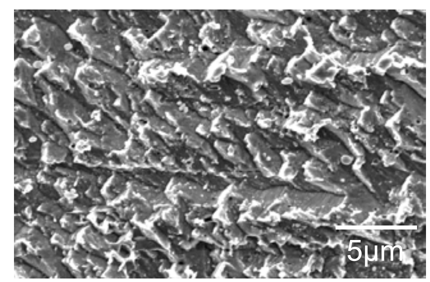
Various copper surface shape

Whisker evaluation process

Whisker test (30°C/60%RH) → Observation of whisker

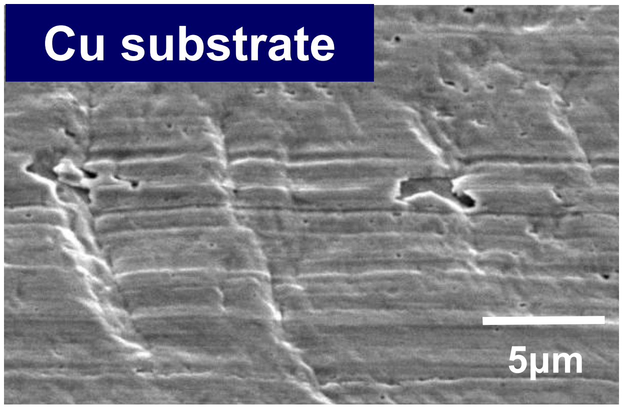
Shape vs. Ra
the copper substrate surface

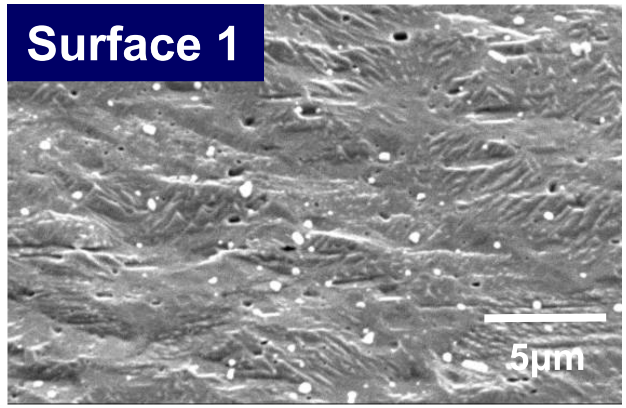
Ra (μm)

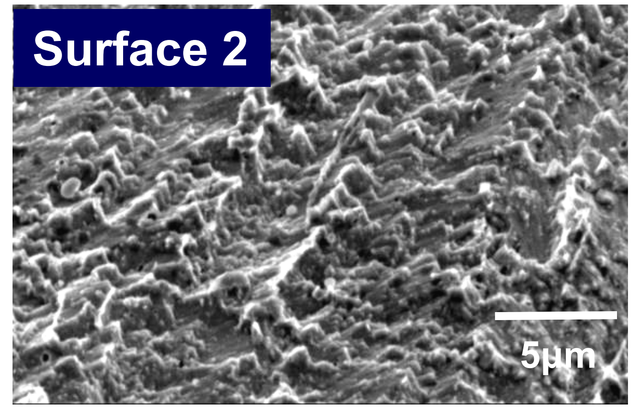
0.087(substrate)	0.120	0.187	0.249
			
0.288	**0.358**	**0.402**	**0.487**
			

Surface shape on copper substrate after etching

Substrate: CDA19400 leadframe / Etching depth: 2μm (average)



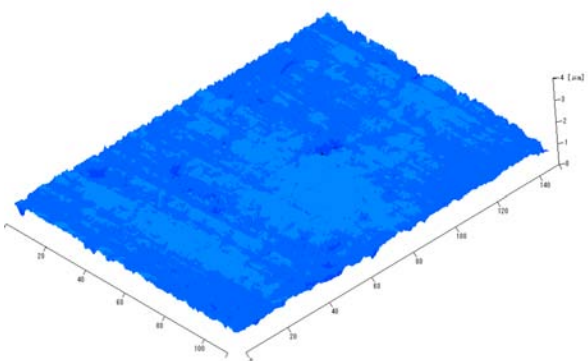


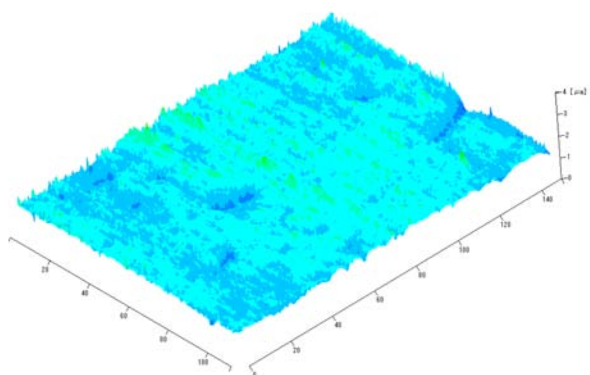


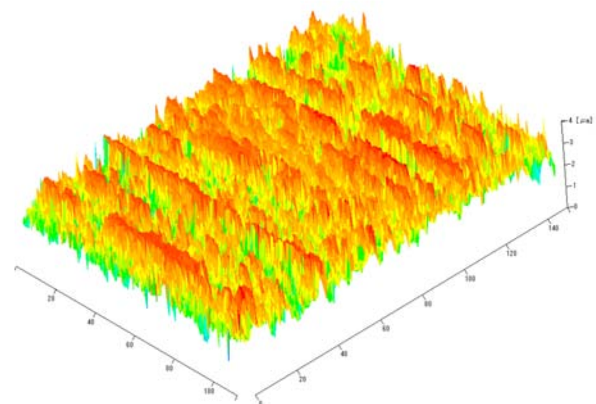
Ra 0.08μm

Ra 0.15μm

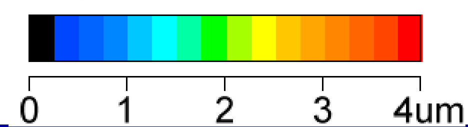
Ra 0.45μm







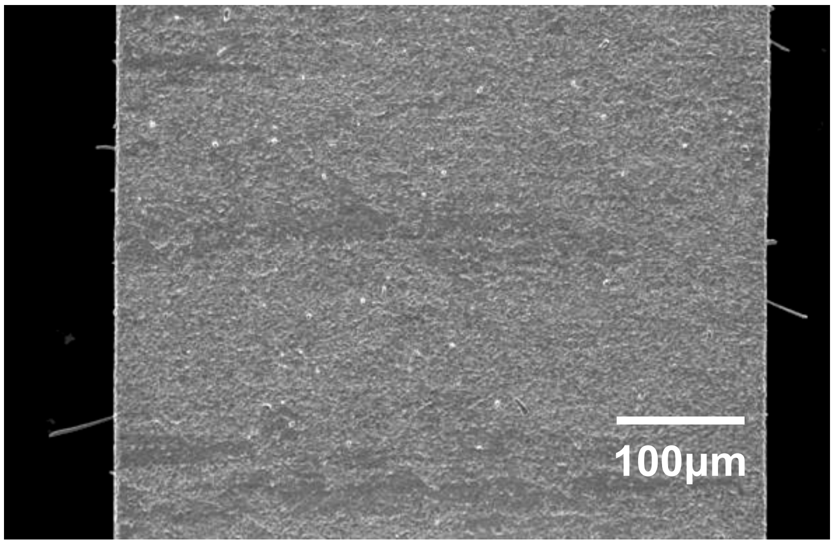
The above 3D roughness map is analyzed by laser micro scope.
Ra: arithmetical mean roughness

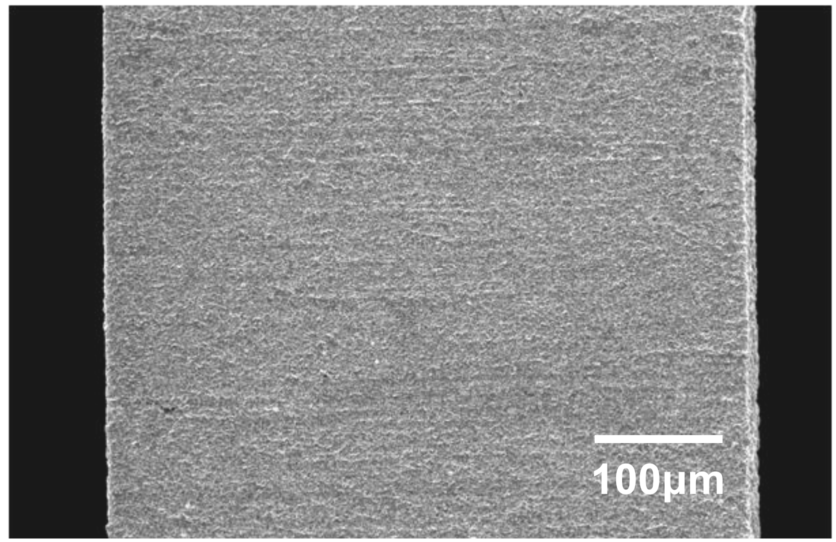


Observation of tin whisker after test

Samples : Tin thickness 3μm

Storage condition : 30°C / 60%RH / 1,000hours





Ra 0.13μm

Surface roughness on Cu substrate

Ra 0.45μm

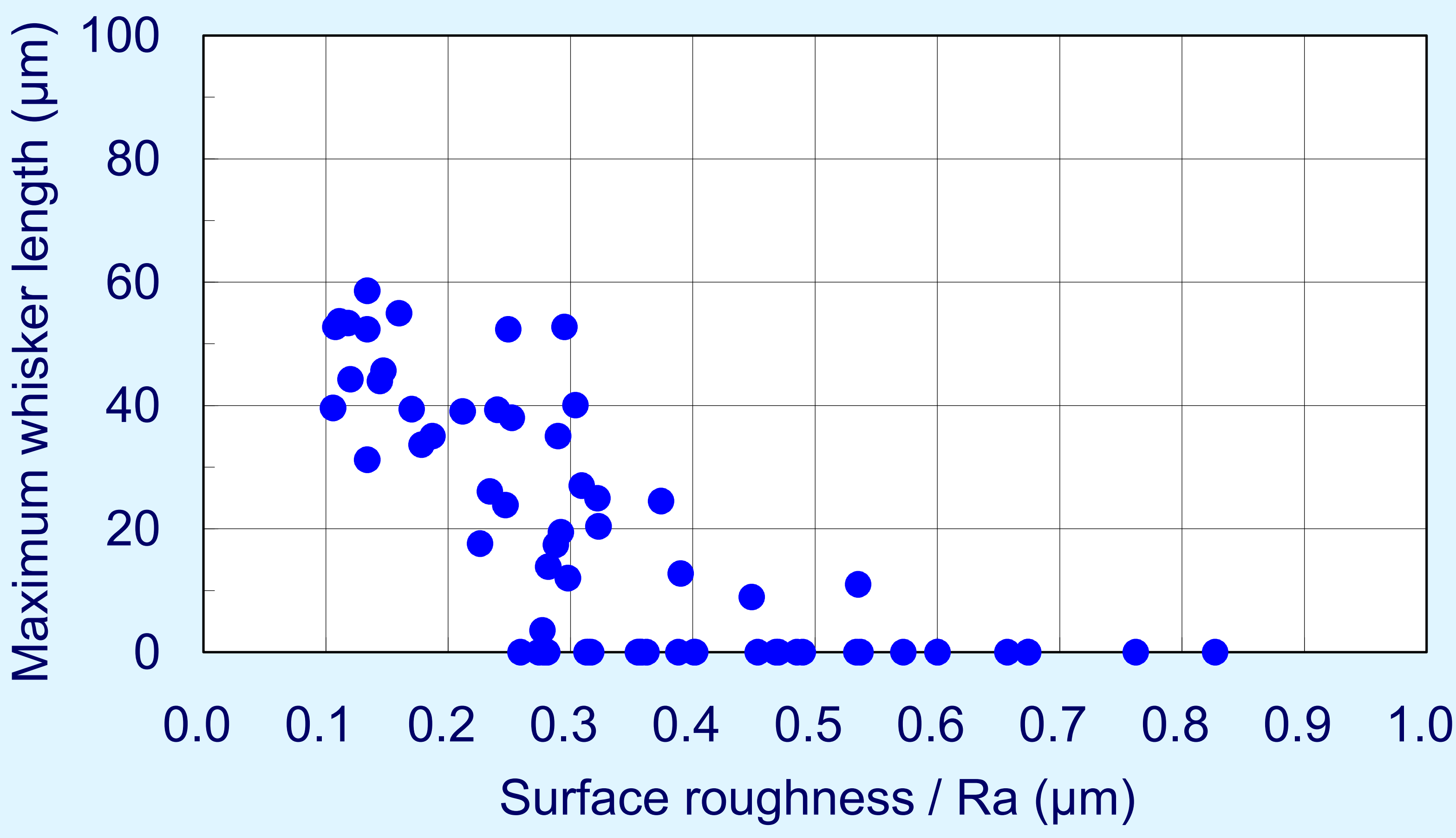
Whiskers were observed.

No whiskers

Maximum whisker length on 3µm thickness tin deposit

Samples : Tin thickness 3µm

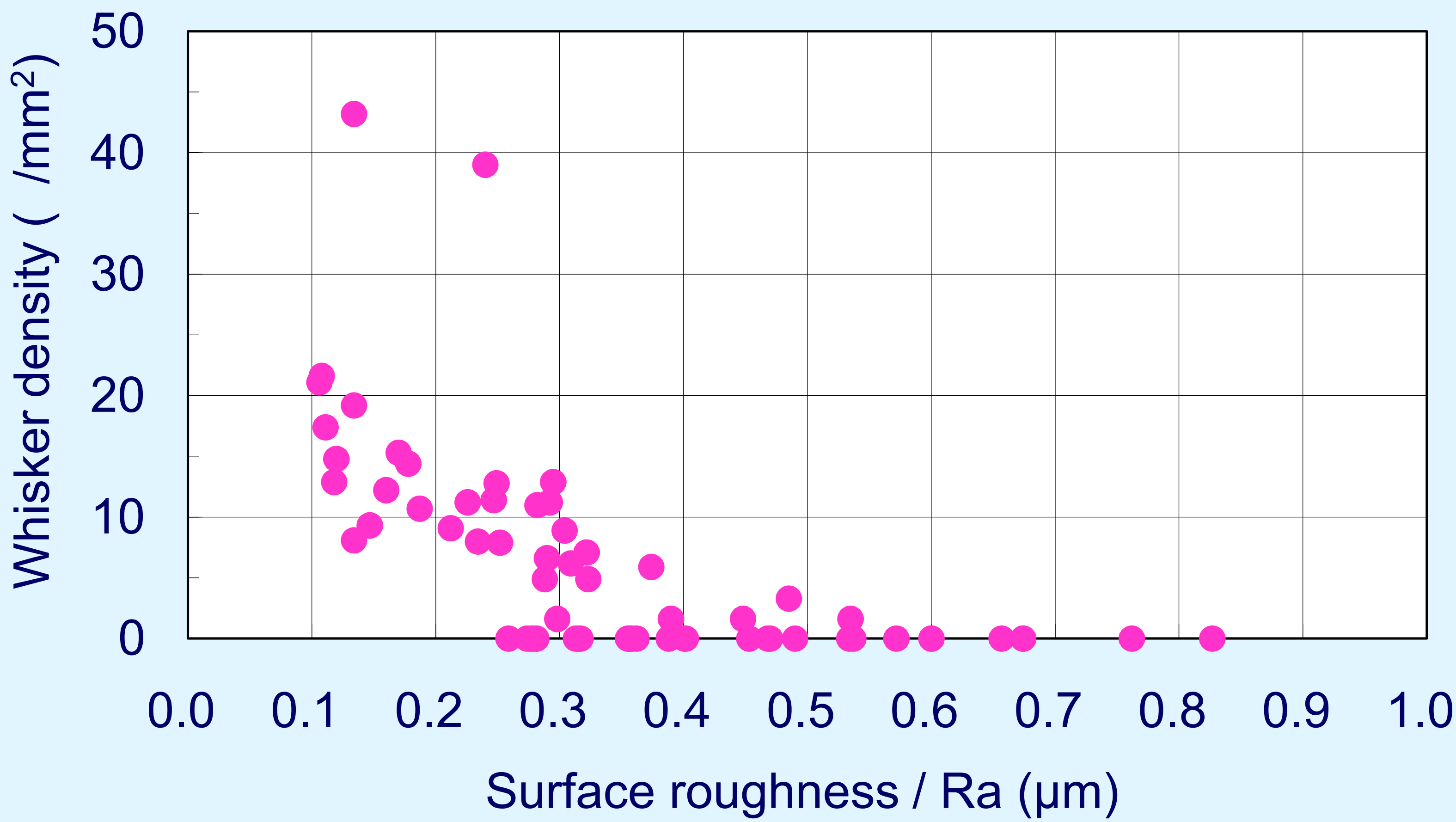
Storage condition : 30°C / 60%RH / 1,000hours



Whisker density
on 3μm thickness tin deposit

Samples : Tin thickness 3μm

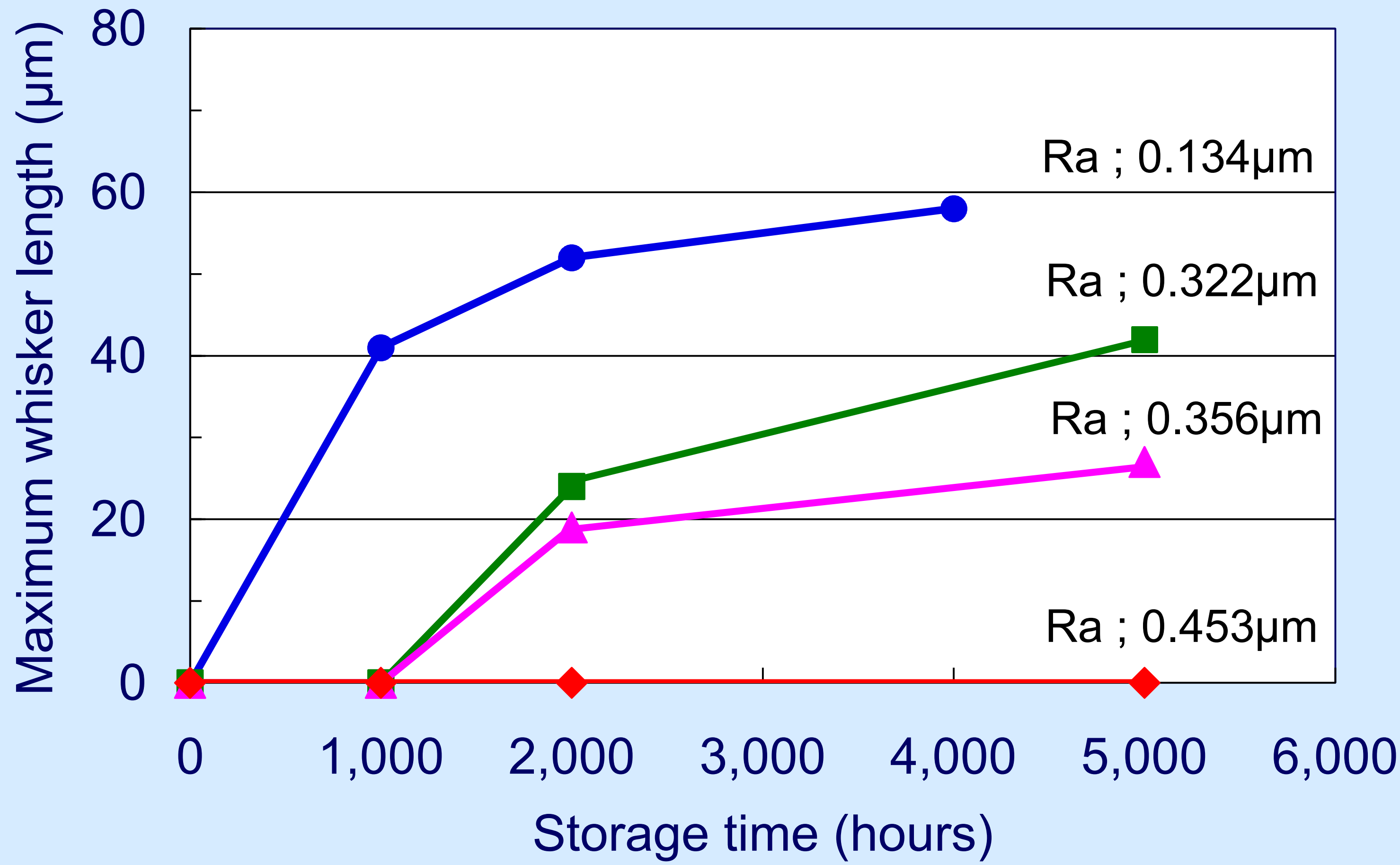
Storage condition : 30°C / 60%RH / 1,000hours



The relation of Maximum whisker length vs. surface roughness

Samples : Tin thickness 10μm

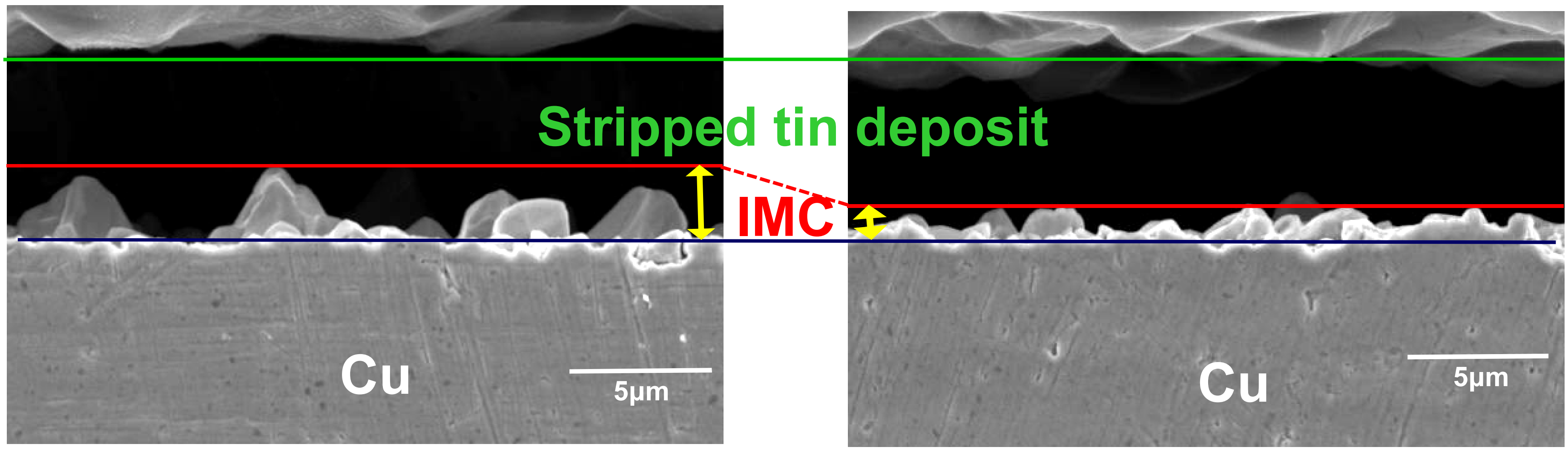
Storage condition : 30^{o}C / 60%RH / 5,000hours



Comparison of the IMC with surface roughness after stripping tin deposit by cross section

Samples : Tin thickness 10µm

Storage condition : 30°C / 60%RH / 7,000hours



Ra 0.13µm

Surface roughness on copper substrate

Ra 0.47µm

- Large IMC grain
- Localized

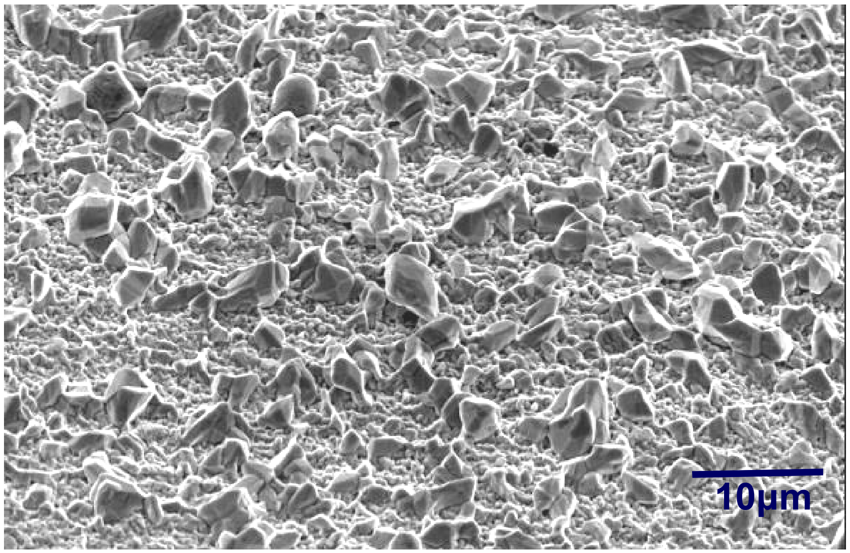
- Small IMC grain
- Comparatively dispersed and uniform

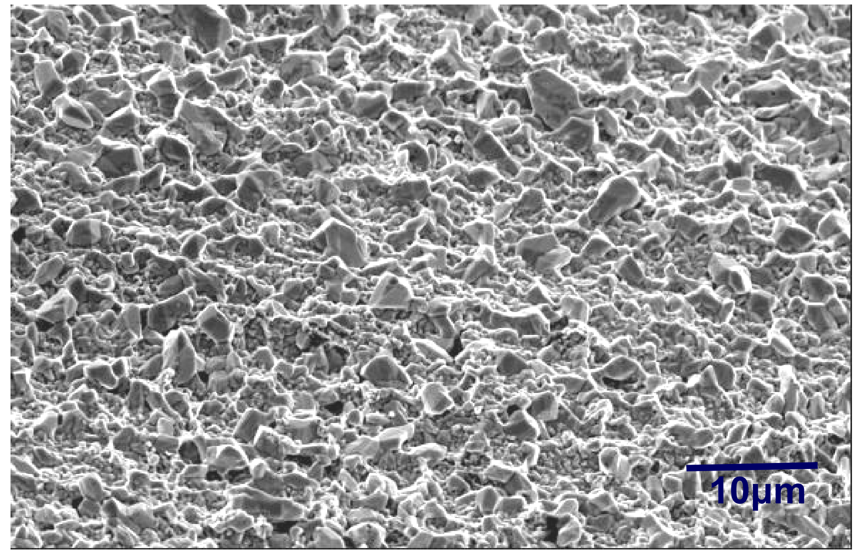
Comparison of the IMC with surface roughness after stripping tin deposit by surface SEM

Samples : Tin thickness 10μm

Storage condition : 30^{o}C / 60%RH / 7,000hours

45^{o} tilt in SEM





Ra 0.13μm

Surface roughness on copper substrate

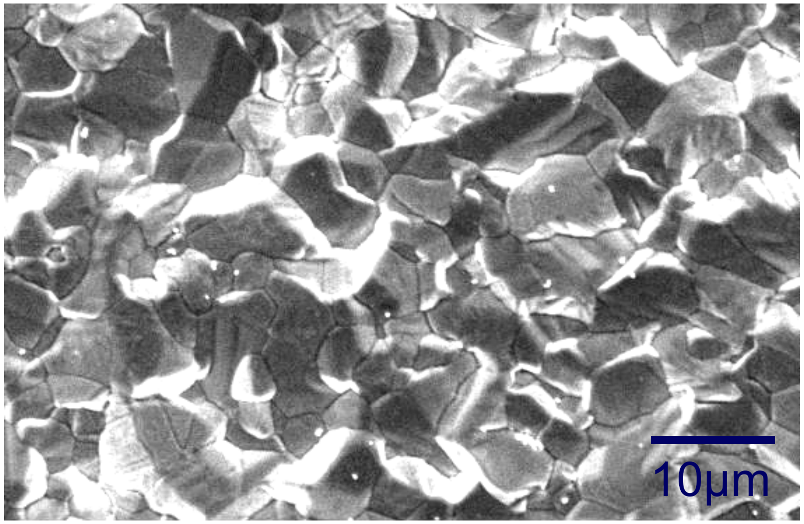
Ra 0.47μm

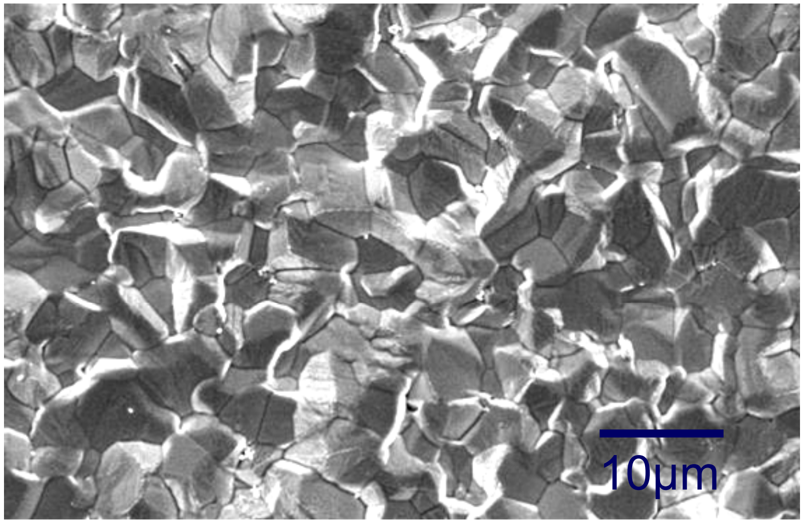
- Large IMC grain
- Localized

- Small IMC grain
- Comparatively uniform

Comparison of the tin surface morphology with copper surface roughness

Tin thickness: 10µm





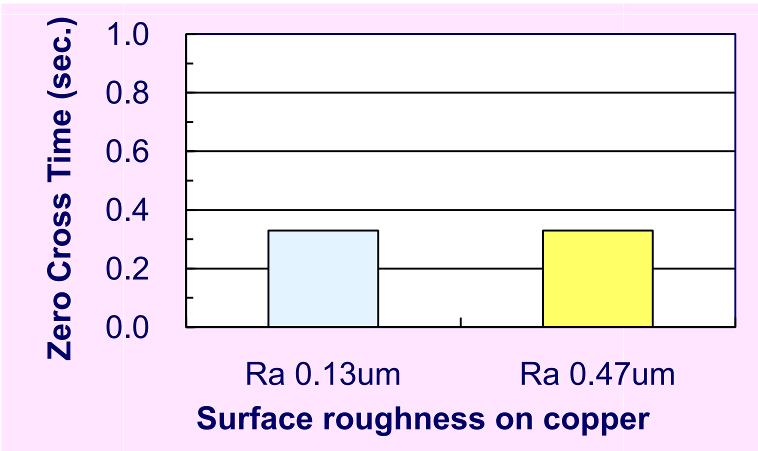
Ra 0.13µm | Surface roughness on copper substrate | Ra 0.47µm

✓Tin deposits on two different copper surfaces had same surface morphology.

Comparison of the tin deposit characters with copper surface roughness

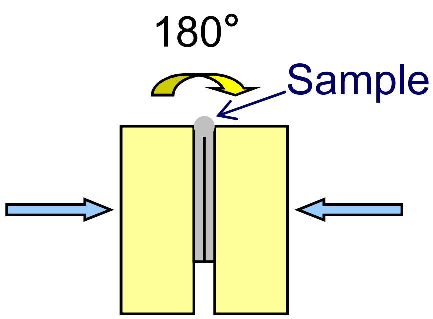
Solderability of tin deposits

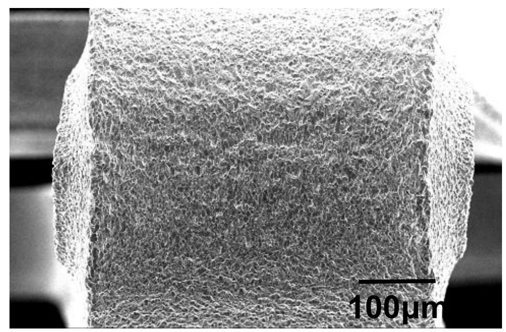
Tin thickness: 10μm

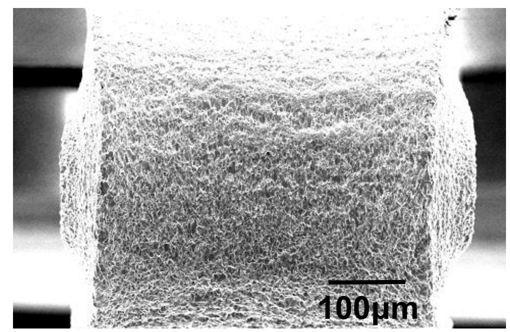


Instrument: SWET-2100 (Tarutin Kester)
Method: Wetting Balance Method
Solder: Sn-3Ag-0.5Cu (Senju Metal Industry / M705)
Flux：CF-110VH-2A (Tamura Kaken)
Temperature: 255^{o}C
Immersion Depth:2mm, Immersion Speed:2mm/sec.

Bending test (ductility)







Ra 0.13μm | Surface roughness on copper substrate | Ra 0.47μm

✓Solderability and ductility of tin deposits on two different copper roughness were excellent. Surface roughness on copper substrate didn't affect properties of tin deposits.

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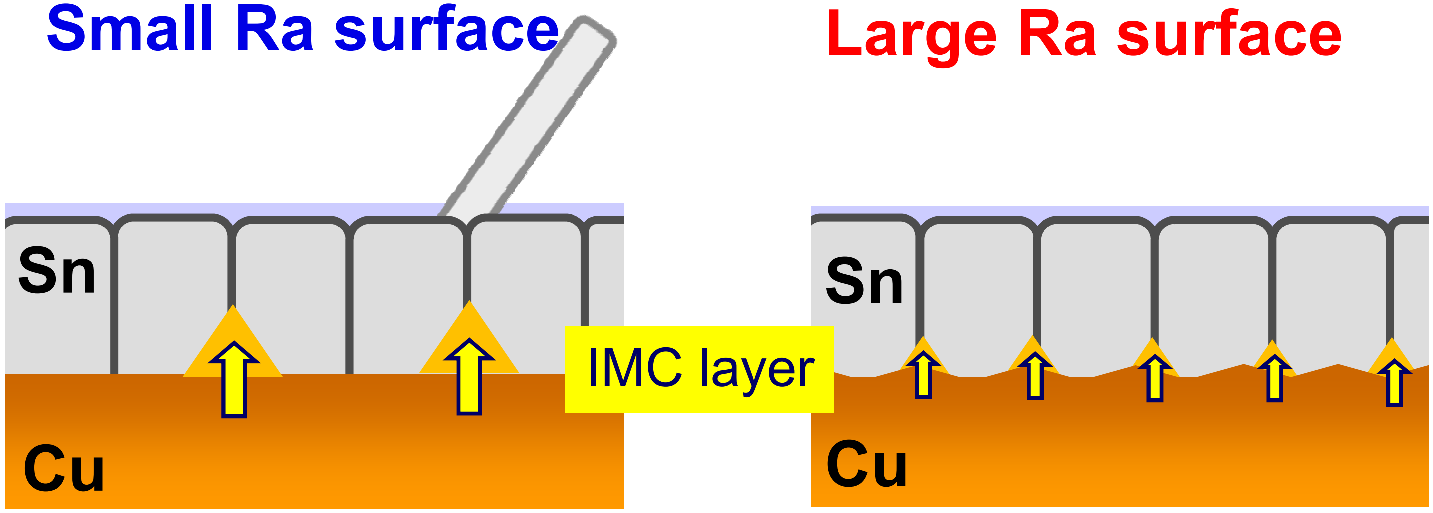
Consideration of tin whisker mitigation by copper substrate roughness

Small Ra surface | **Large Ra surface**



General understanding

- Large IMC
- Localization

Localized compressive stress is generated in tin deposit.

Tin whisker is formed.

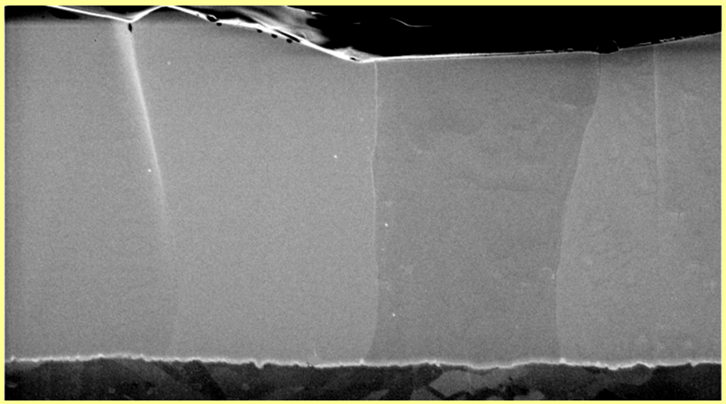
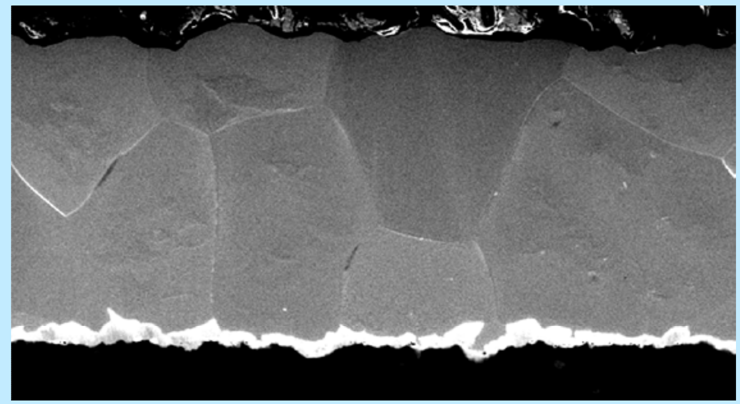
- Small IMC
- Comparatively dispersed and uniform IMC layer

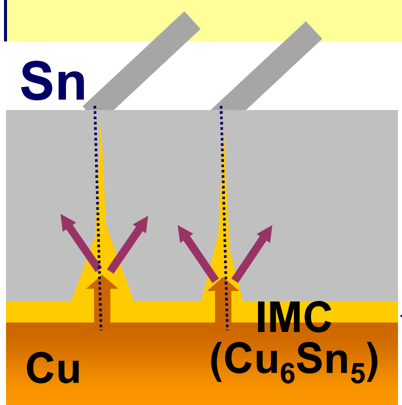
Localized compressive stress in tin deposit is relieved.

Tin whisker is reduced.

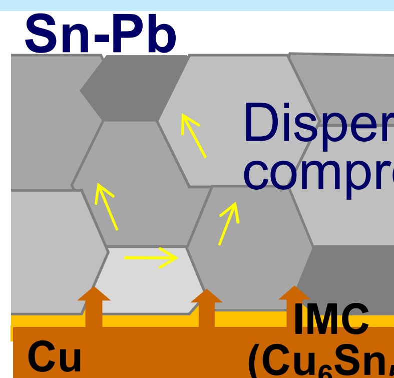
Study of
The crystal structure of tin deposit
vs.
Tin whisker formation

Checked the different crystal structure of the tin deposit and tin-lead alloy deposit

	Whisker formation Typical tin deposit	**Whisker prevention** Tin-lead alloy deposit
Cross section		
Crystal structure	Column structure	Equiaxed structure



Irregular growth of IMC



Uniform IMC layer

Experiment

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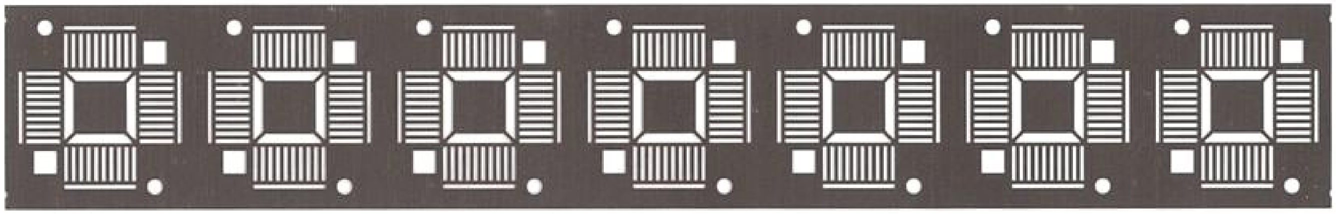
Test vehicle

- CDA19400 (Cu-2.3Fe-0.03P-0.12Zn) leadframe
  (Original leadframe)



Tin plating

- Plating bath : MSA matte tin plating bath
  : Three tin plating baths with different additives
- Cathode current density : $10A/dm^2$
- Thickness ; 10um (typical thickness for leadframe)

The evaluation method of tin whisker formation

Whisker test

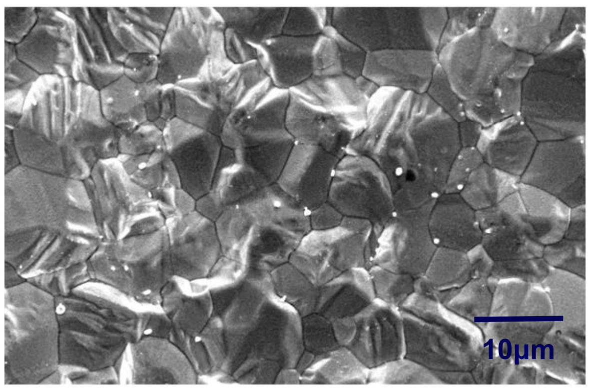
- Storage condition : 30^{o}C / 60%RH
- Storage time : more than 4,000hours
- Parameter : Maximum whisker length
  Whisker density
- Definition of whisker
  Aspect ratio (long/diameter); more than 2
  Whisker length; more than 10um
- Measurement method of whisker length; JEITA ET-7410
  The straight line distance from the point of emergence of the whisker to the most distant point on the whisker.

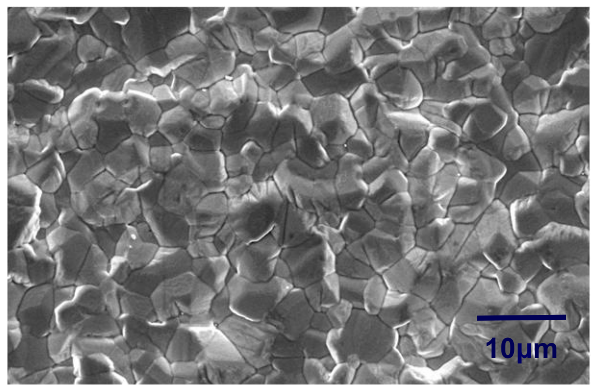
Three kinds of tin deposit

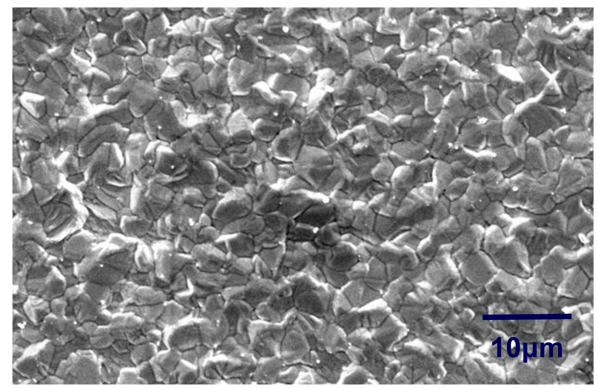
Kind of tin deposit		Type A	Type B	Type C	
Grain size	Large	>	>		Small
Crystal structure		Column	Column	Column + Equiaxed	
Appearance of deposit		matte	matte	matte	
Carbon content in deposit (wt%)		0.001	0.001	0.001	

Surface morphology - Grain size -

Type A	Type B	Type C

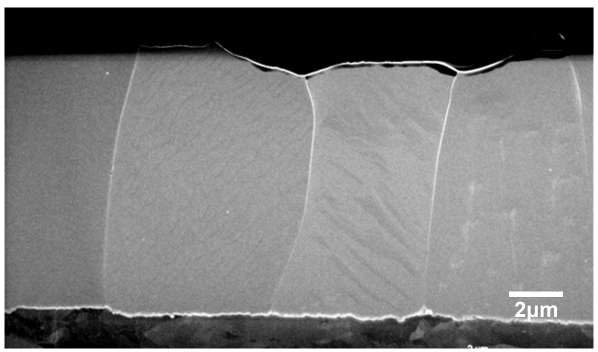
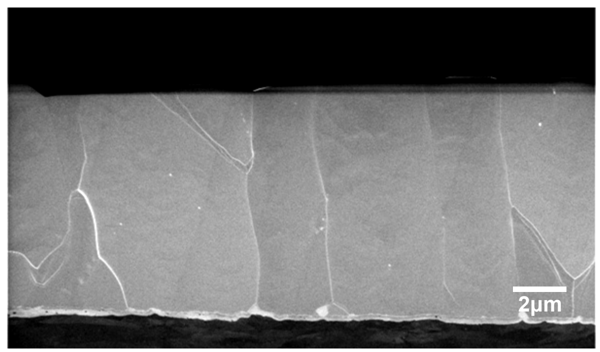
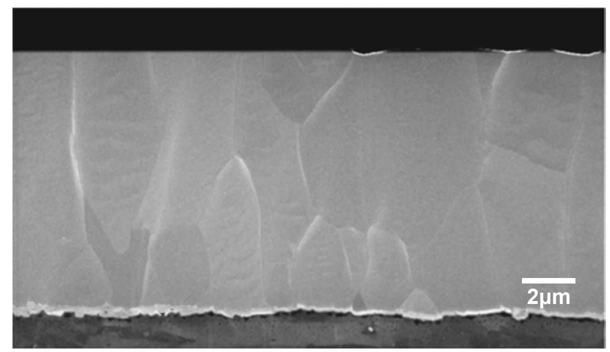






Large > > Small

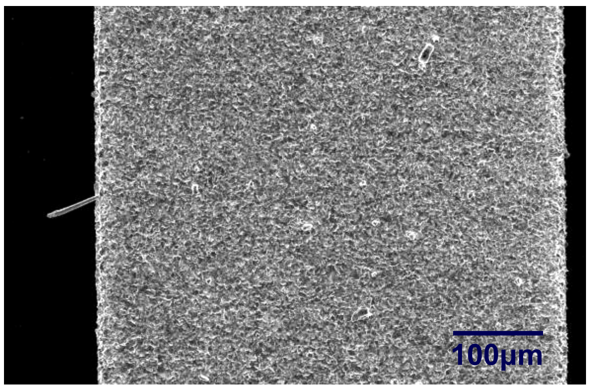
Crystal structure - Cross section -

Type A	Type B	Type C
		
Column structure	Column structure	Column + Equiaxed structure

Observation of tin whisker after test

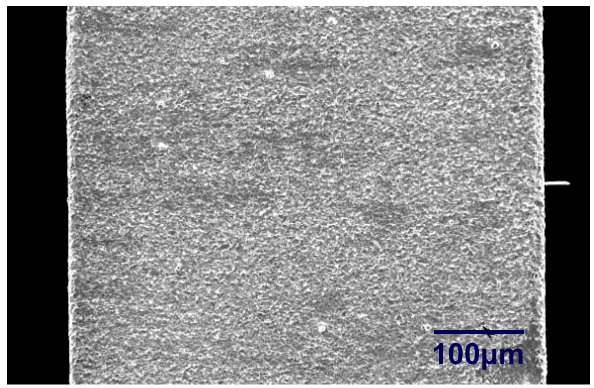
Samples : Tin thickness 10µm
Storage condition: 30^{o}C / 60%RH / 4,000hours

Type A



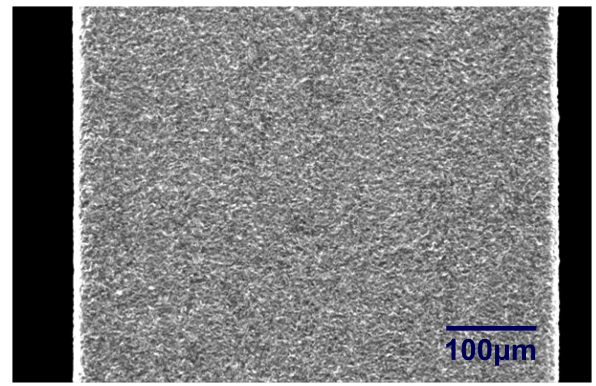
Whiskers were found.

Type B



Whiskers were found.
Whiskers were shorter than Type A.

Type C

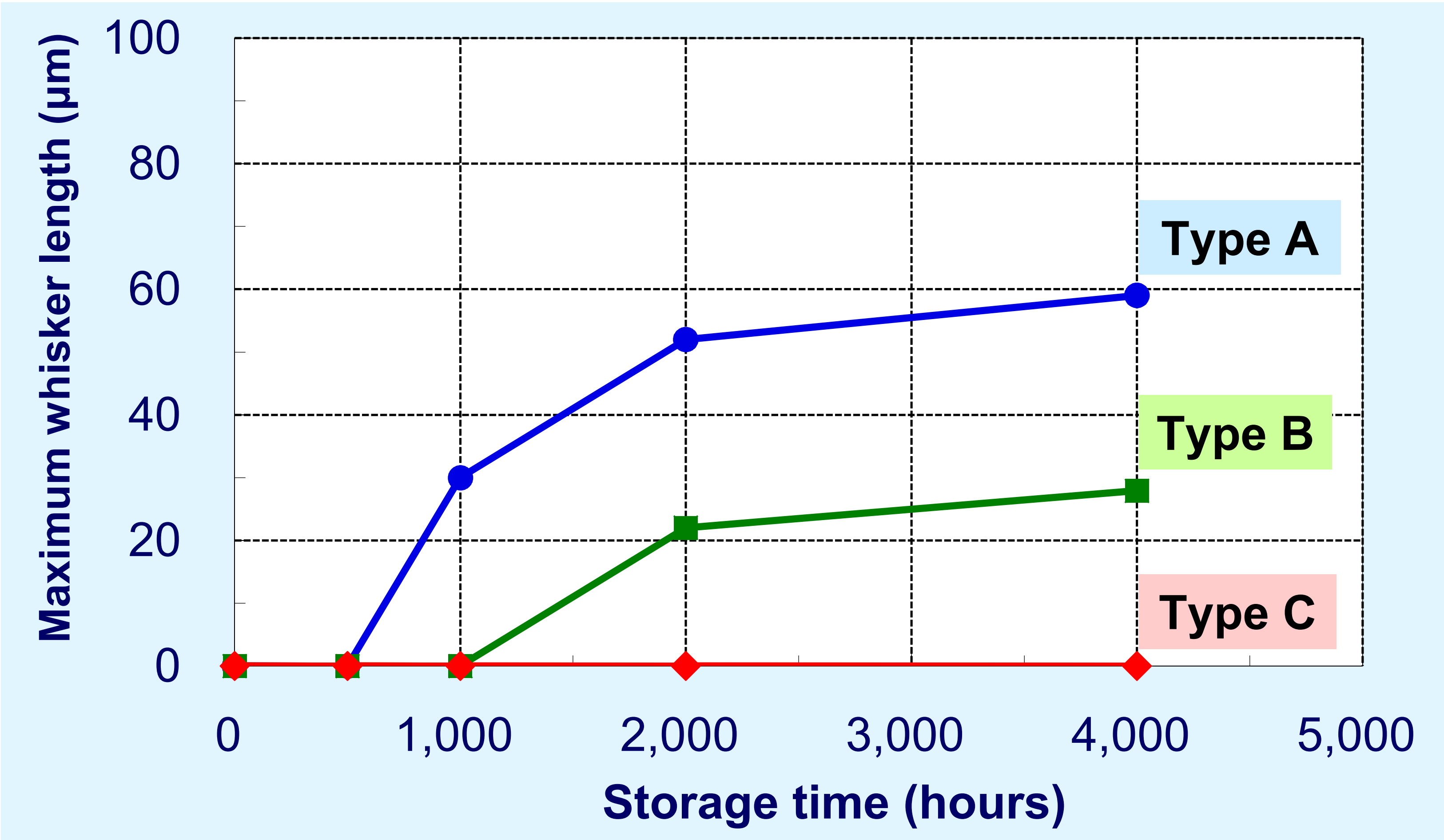


No whiskers

Maximum whisker length

Samples : Tin thickness 10μm

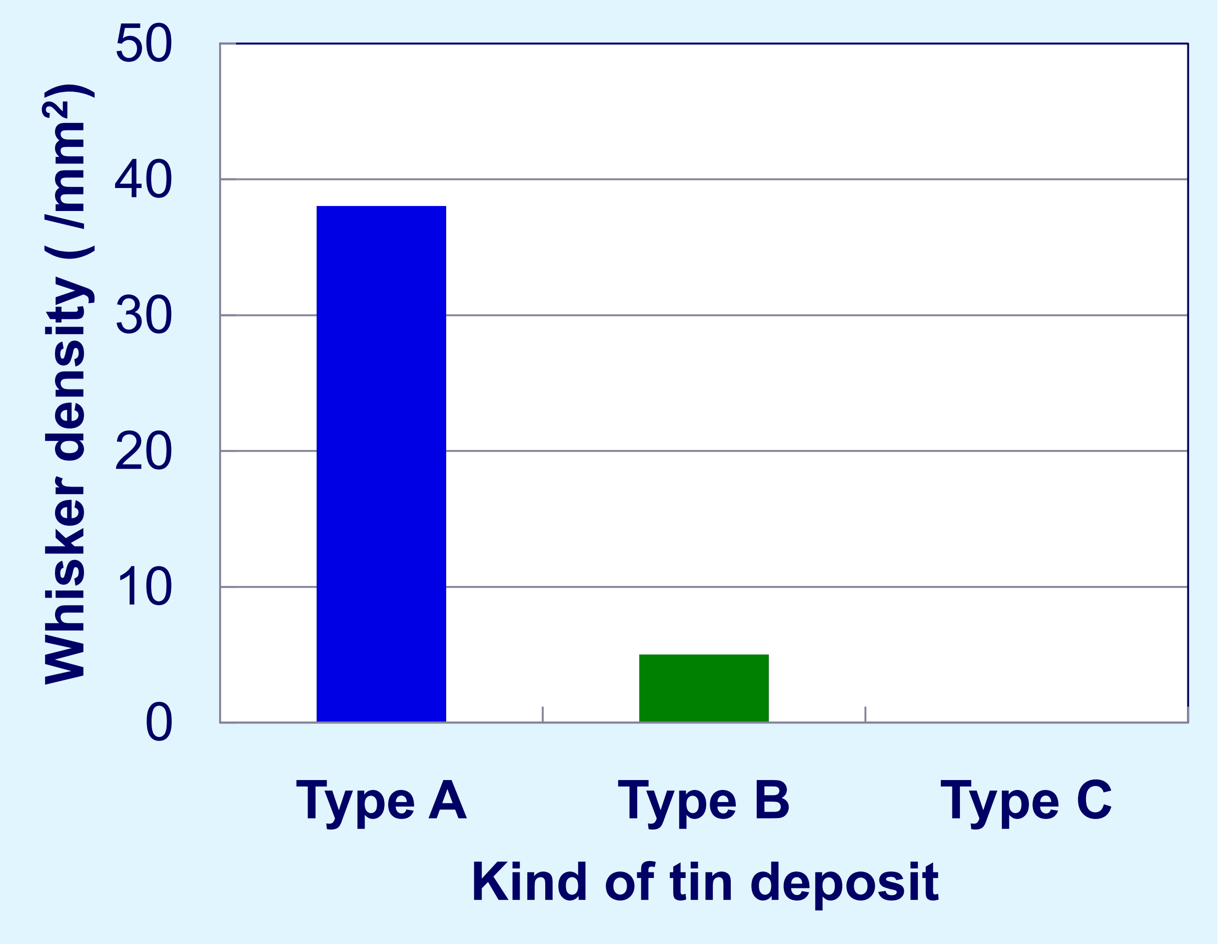
Storage condition: 30°C / 60%RH / 4,000hours



Whisker density

Samples : Tin thickness 10μm

Storage condition: 30°C / 60%RH / 4,000hours

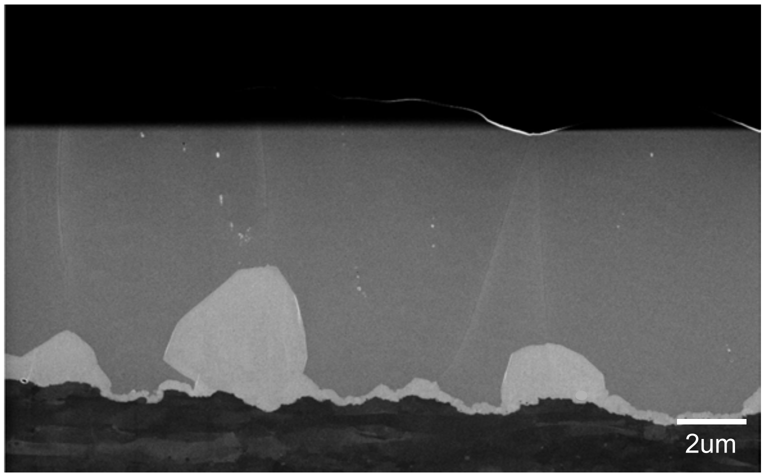


Cross-section after 22,000hours at 30°C / 60%RH

Samples : Tin thickness 10μm

Storage condition: 30°C / 60%RH / 22,000hours

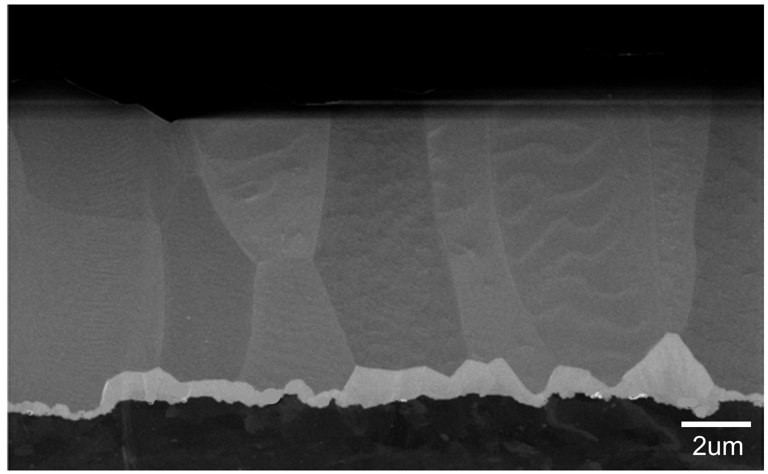
Type A



Whiskers were found.

- Large IMC grain
- Localized

Type C



No whiskers

- Uniform IMC layer

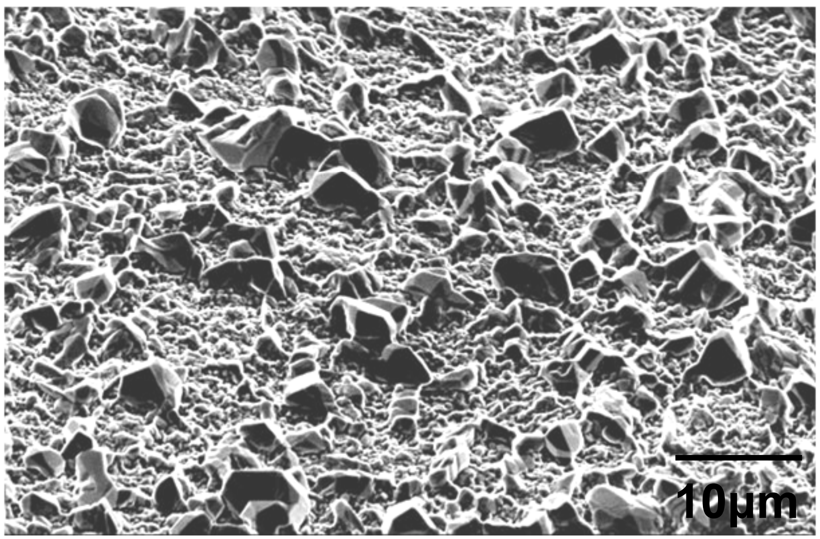
Observation of surface of IMC layer after stripping tin deposit

Sample : Tin thickness 10µm

Storage condition : 30^{o}C / 60%RH / 22,000hours

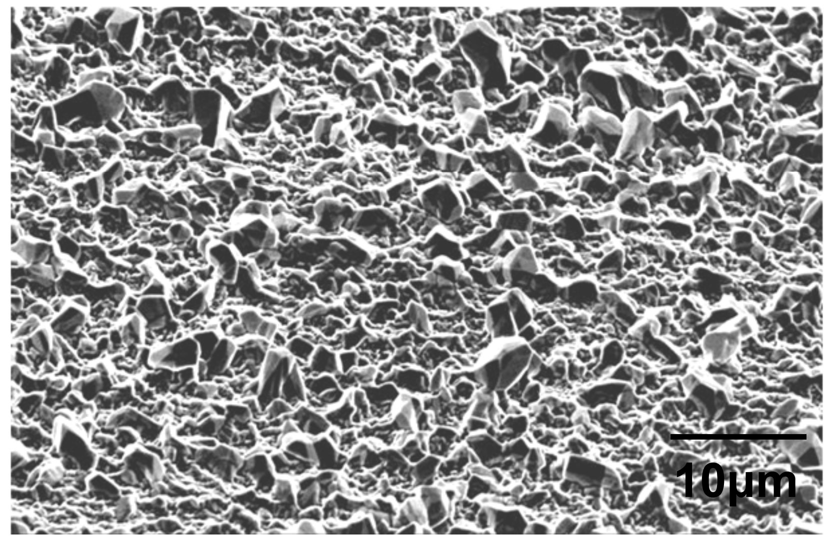
45^{o} tilt in SEM

Type A



- Large IMC grain
- Localized

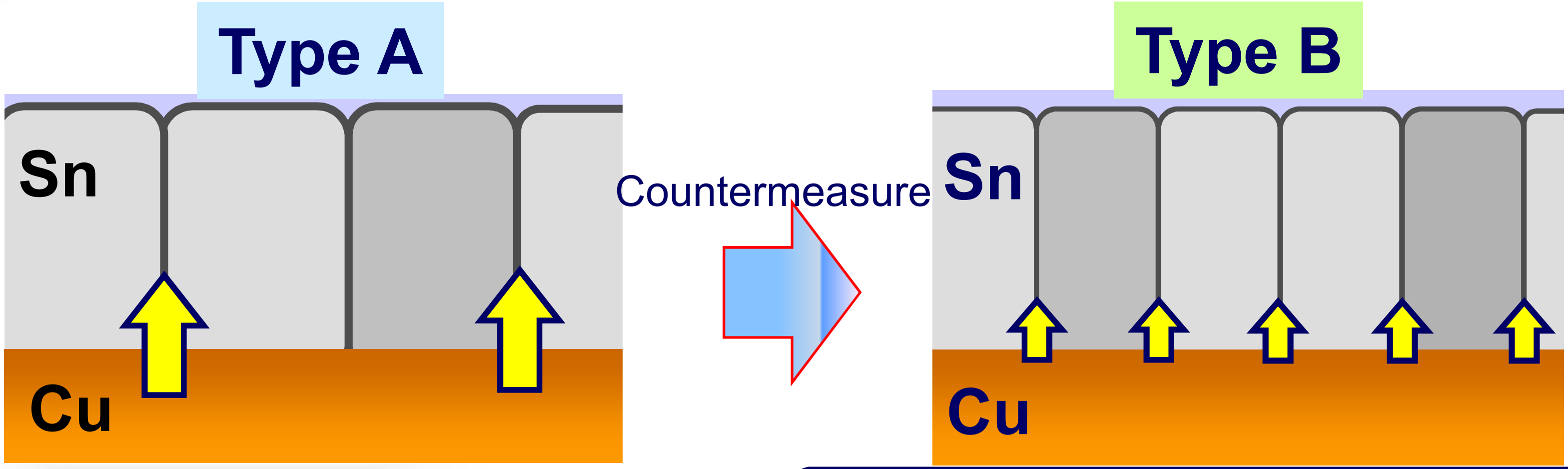
Type C



- Small IMC grain
- Comparatively uniform

UYEMURA

Consideration of the tin whisker mitigation - Type B -



General understanding

Type A	Type B
Tin grain size is large. >> a few grain boundaries	Tin grain size is small. >> many grain boundaries
Large IMC grow into grain boundaries at local places.	Dispersion of copper diffusion
Localized compressive stress is generated in tin deposit.	Small and uniform IMC layer
	Low compressive stress in tin deposit
Tin whisker growth	**Tin whiskers are reduced.**

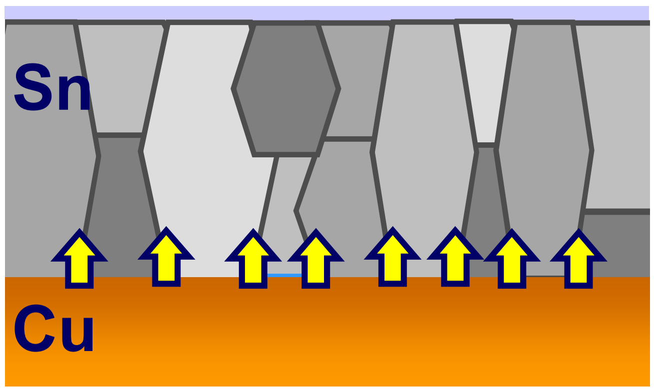
Considering of the tin whisker mitigation
- Type C -

Type A

Countermeasure

Type B

Type C



Tin grain size is smaller.
>> many grain boundaries
+
Equiaxed and column structure

Dispersion of copper diffusion

Small and uniform IMC layer

Grain boundary diffusion of tin disperses and slows.

Compressive stress in tin deposit is relieved more.

Tin whiskers are restrained.

Summary

◆<u>Effect of copper substrate roughness</u>

- Tin deposit on copper substrate that was formed large Ra by etching reduced tin whiskers at ambient conditions. It was thought that the uniform IMC layer prevented accumulating internal stress into tin deposit.

◆<u>Effect of crystal structure in tin deposit</u>

- Compared with large grain size tin deposit, tin deposit that had small grain size reduced tin whisker formation at ambient conditions.
- Tin deposit which had crystal structure similar to tin-lead deposit restrained tin whisker formation effectively.
- Crystal structure in tin deposit is one of the most important factors to restrain tin whiskers.