A Study of Reliability between Solder Alloy and Pad Materials

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EXECUTIVE SUMMARY

The low Ag solder alloy shows higher drop performance than the high Ag solder alloy in the every kind of package and board combinations. This is related to the ductility of solder and the surface between solder and pad.

The unstable interface exists in IMC, pad material, and solder bulk, aroused by the lattice mismatch, which enables the thermal and physical stress due to the continuous exterior shock to transfer to the IMC interface. Therefore, it must be strongly requested to control solder morphology, and also shape and thickness of IMC for improving the solder reliability.

Furthermore, the solder alloy with high Cu shows good drop performance. We can analogize from this Cu performance that high Cu plays an important role in relieving the brittle surface, such as Ni-P layer, being appeared on electro-less pad after reflow.

A study of reliability between solder alloy and pad materials

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2. Aim of this study
3. Basic properties with various Cu contents
4. Reliability test with various Cu contents
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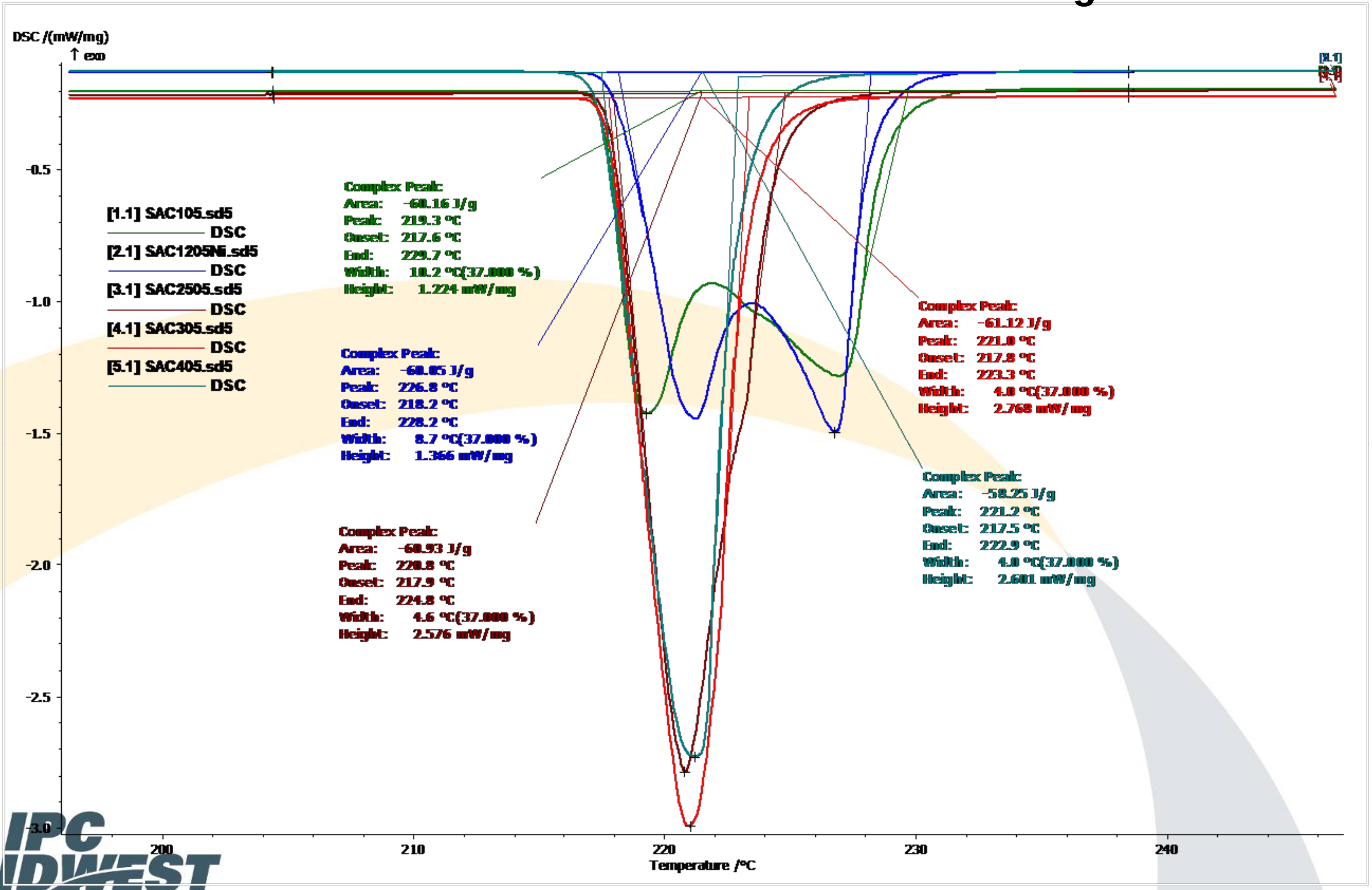
Basic properties with various Ag contents

-. Heating rate : 10℃/min.



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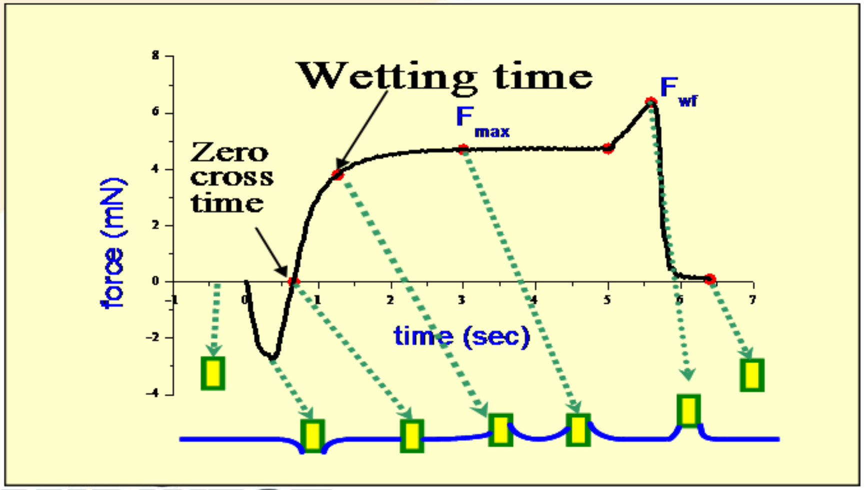
Basic properties with various Ag contents

Test condition

Test sample	Flux	Temp.	# of test	Test machine	Remark
Variable Ag contents	WS-type	240 ℃	3	Malcom. SP-2	J-STD-002B

- Test coupon : Cu-OSP treatment (0.2*3*10mm)



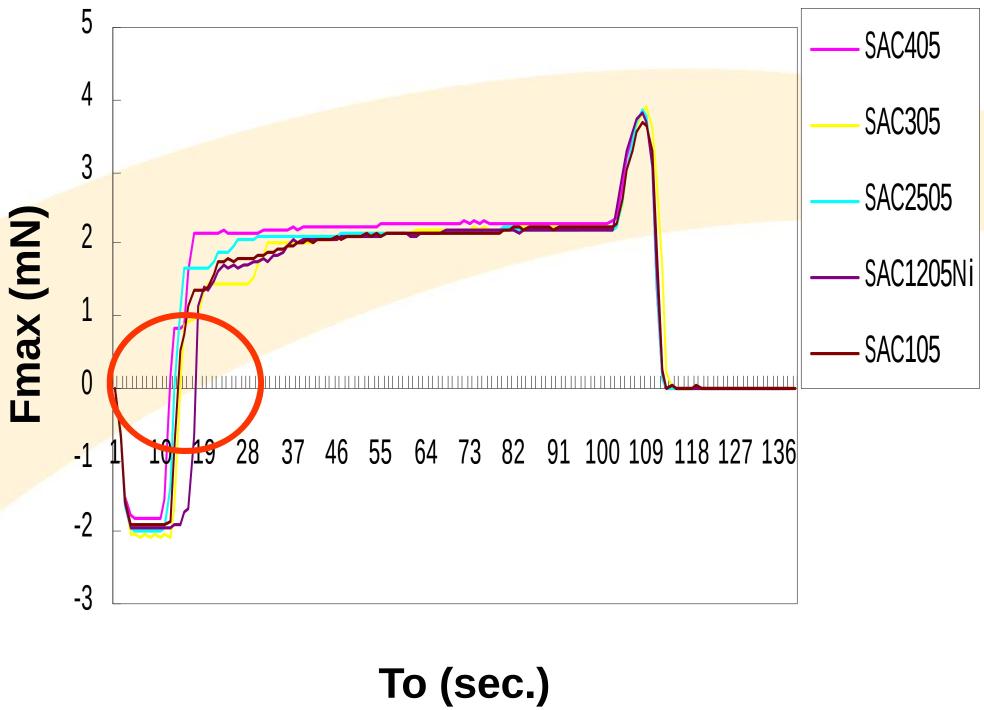
Wetting curve

1. F_{max} : Max. wetting force.
2. F_{end} : Finish wetting force.
3. T_0 : Time to buoyancy corrected zero.
4. T_1 : The time taken to reach 2/3 of the maximum force during the test.
5. Sb : Wetting stability. Fend / Fmax

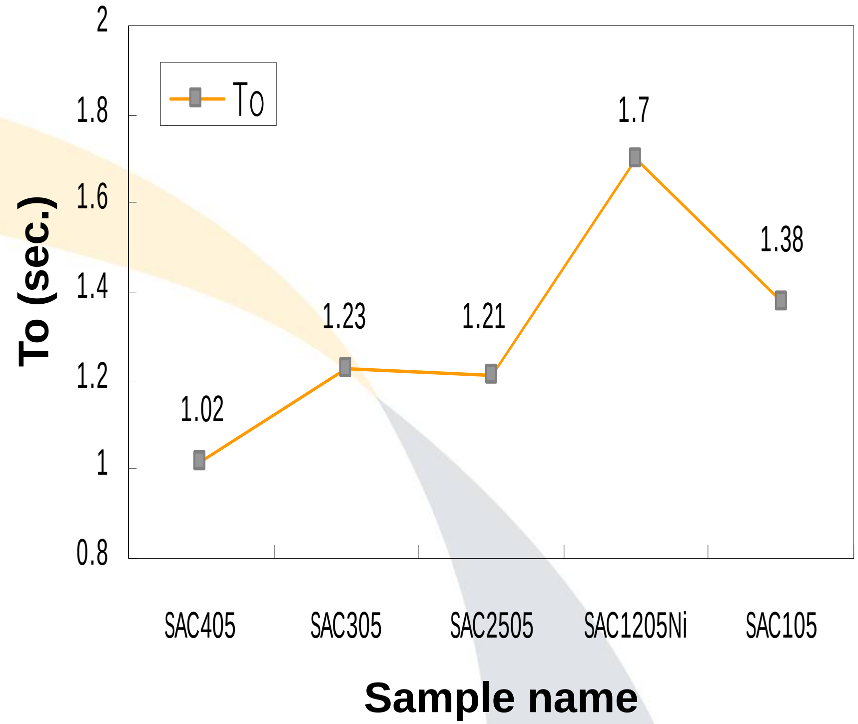
Basic properties with various Ag contents

Wet-ability test

-. Wet-ability



-. Wetting time



Basic properties with various Ag contents

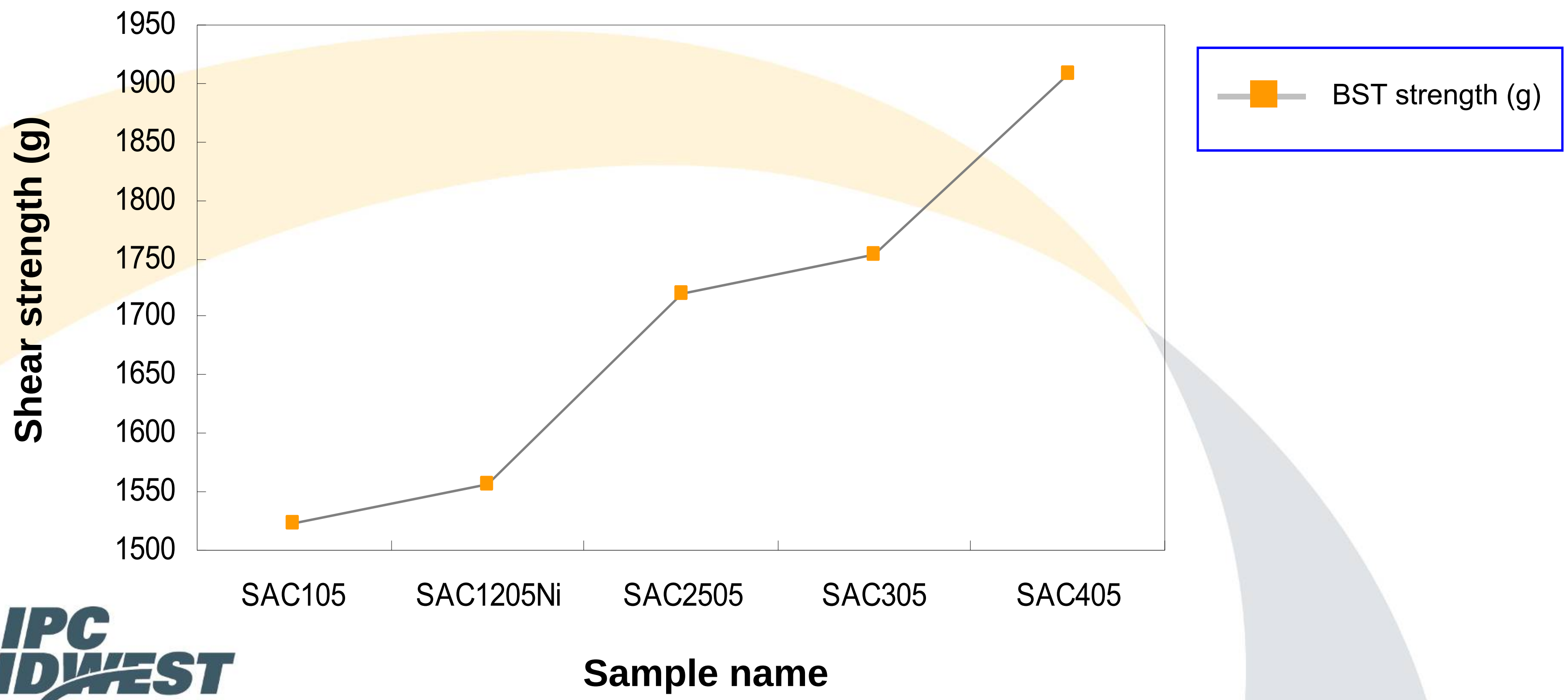
Ball Shear Test

-. Test speed : 700㎛/s

-. Ball size : 760㎛

-. Shear height : 20㎛

-. Package : ENIG

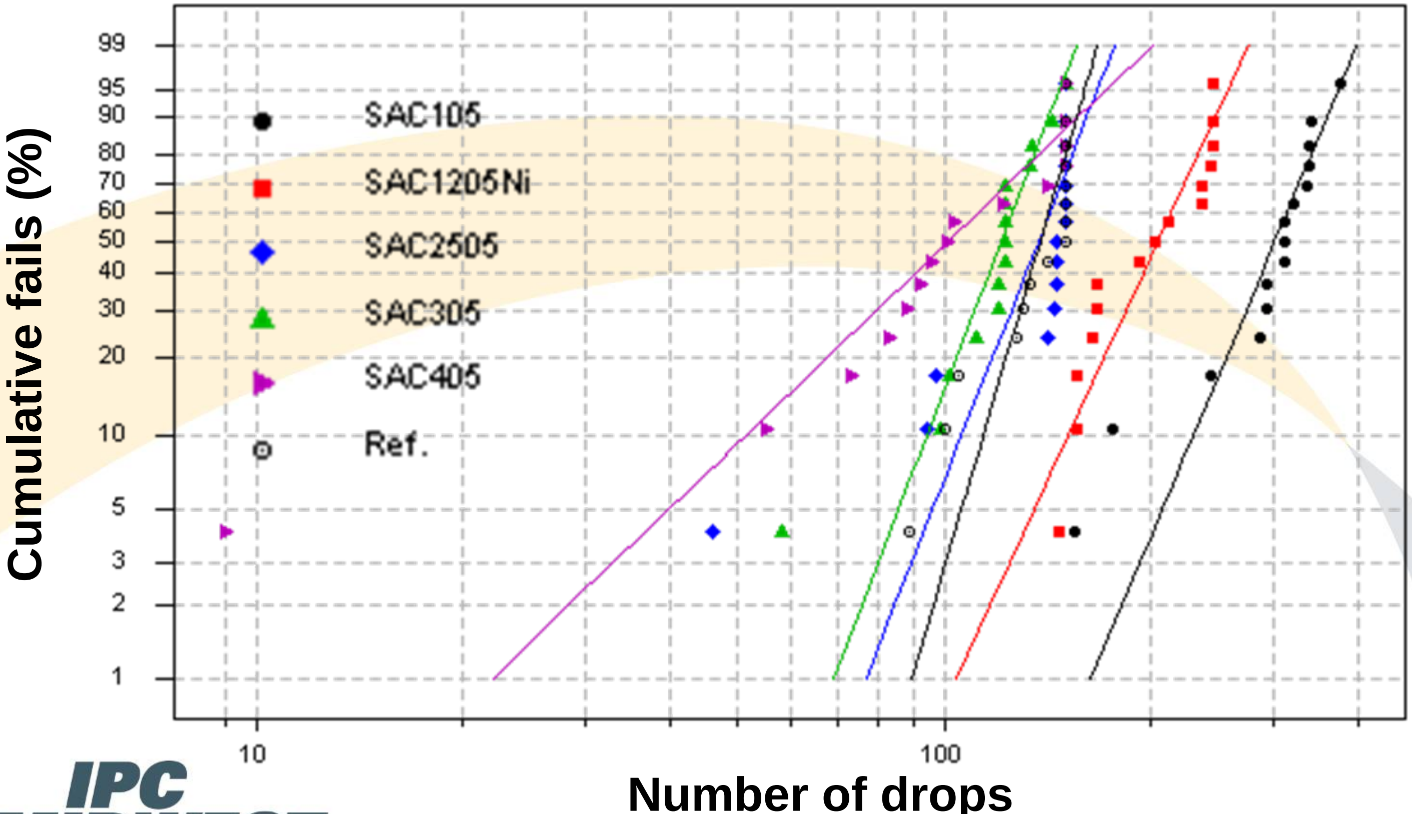


Basic properties with various Ag contents

Drop strength

-. The acceleration reaches about 900G (±50) upon impact. (activated time : about 0.7msec)

-. Drop shock failure result is analyzed by Weibull method.



-. Drop height : 300mm

-. Acceleration : 900G

-. Count : 400 drops

-. Package : Ni/Au

-. Board : Cu-OSP

-. Flux : WS type

-. Ball size : 0.76mm

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Basic properties with various Ag contents

- **Properties of variable compositional solder alloy**

Composition	Shear strength	Pull strength	Hardness	Wet-ability	Mush Zone	Drop strength	Thermal cycling	Extrude Ag_3Sn	Remarks
SAC105	**Weak**	**Weak**	**Weak**	Worse	Wide	**Good**	**Worse**	**Weak**	**Good for Ni/Au pad**
SAC1205-0.05Ni				Worse	Wide	**Good**	**Worse**		**Good for Cu-osp pad**
SAC2505				Good	Narrow	**Good**	**Good**		
SAC305				Good	Narrow	**Worse**	**Good**		
SAC3505				Good	Narrow	**Worse**	**Good**		
SAC405	**Strong**	**Strong**	**Strong**	Good	Narrow	**worse**	**Good**	**Extrude**	

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A study of reliability
between
solder alloy and pad materials

Aim of this study

	Electroless Ni plating (ENIG)	Electroless Pd plating (ENEPIG)
Merit	-. Widely & generally used. -. Good shelf life (~12 months). -. Handling tolerance.	-. Excellent solder-ability. -. Good shelf life (~12 months). -. Conductive surface for electrical test.
Demerit	-. Industry variations due to different process chemistries. -. The most challenging PCB process requires sophisticated controls.	-. Solder joint strength is highly Pd thickness dependent. -. Process complexity-over and above ENIG complexity.

-. It is a very difficult to control Ni-P layer to be shaped after reflow

-. We need to develop solder ball, which controlled the Ni-P layer,

to improve the solder reliability.

Method for developing

Solder ball	Test items	Test machine		Test condition
			Model (maker)	
Variable Ag contents solder ball	Solder ball Image	Optical spectrometer	(OLYMPUS)	X500, X1,000
	Discoloring test	Reflow oven	1707EXL (HELLER)	Peak temp. : 240℃
	DSC test	DSC	DSC200F3 (NETZSCH)	Heating rate : 10℃/min
	Wetting test	Wet-ability test	SP-2 (MALCOM)	Bath temp. : 240℃
	Hardness test	Micro hardness	FM-700 (FUTURE-TECH)	100g X 30 sec.
	Ball shear test	BST	DAGE 4000series (DAGE)	Speed : 700um/sec Height : 20um
	Drop strength	Drop tester	SD10 (LAB)	Acceleration : 1,500G
	Thermal cycling test	TC test	JYT-S-100 (JINYOUNG)	-40℃ ~ 125℃
	IMC observation	FE-SEM	JEOL 6500F	X3,000

Test leg

Test Item		Surface finish	Solder ball	Size	Type
Package level	IMC	ENIG, ENEPIG	-. Sn 1.0Ag -. Sn 1.0Ag 0.5Cu -. Sn 1.0Ag 1.0Cu -. Sn 1.0Ag 1.5Cu -. Sn 3.0Ag 0.5Cu	0.45 mm	1. ENEPIG (P*) - OSP(B*) 2. ENIG (P) - OSP(B)
	Shear				
Board level	Drop				
	F/M				

P* : Package (Pad), B* : Board

ENEPIG pad spec.

-. Model : CM1900

	Au (um)	Pd (um)	NiP (um)
Group	10	10	10
Ave.	**0.072**	**0.112**	**5.712**
Min.	0.068	0.108	5.544
Max.	0.076	0.116	5.943
Std.	0.002	0.003	0.161

Ball assembly condition

Reflow machine

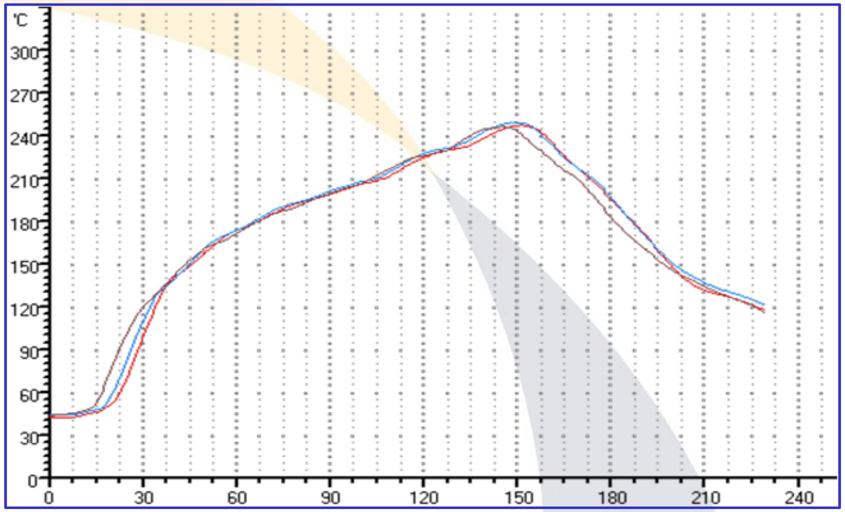
-. Model : HELLER 1707 EXL

-. Peak temp. : 247℃

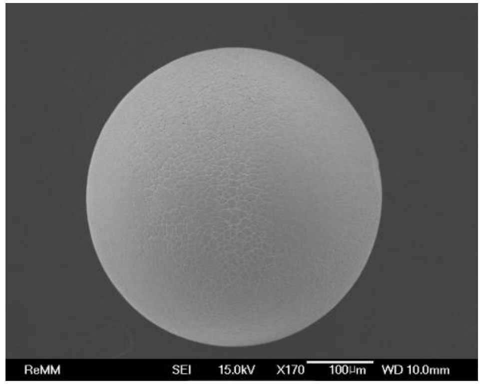
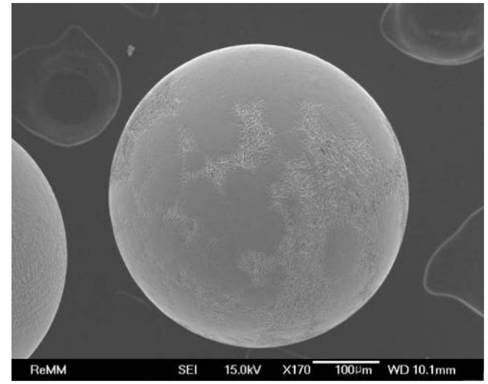
-. Dwell time : 50 ~ 55 sec

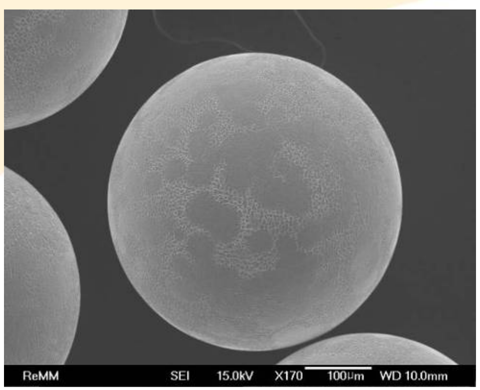
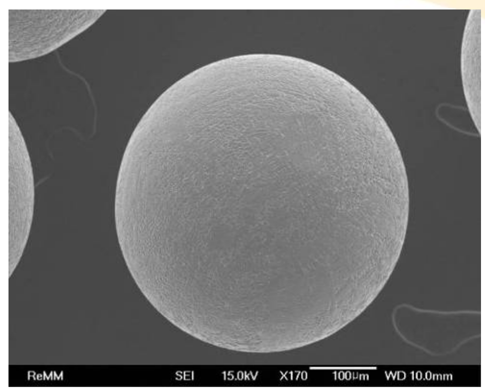
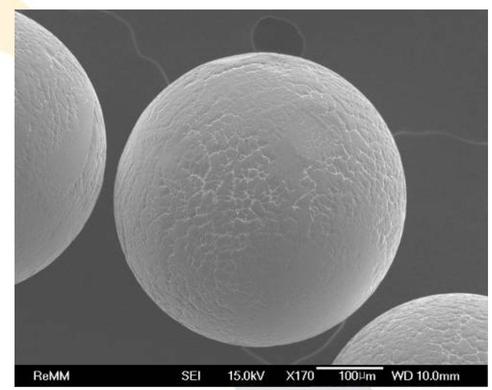
-. Belt speed : 70 cm/min

-. Flux: WF6063M5 (Water soluble)

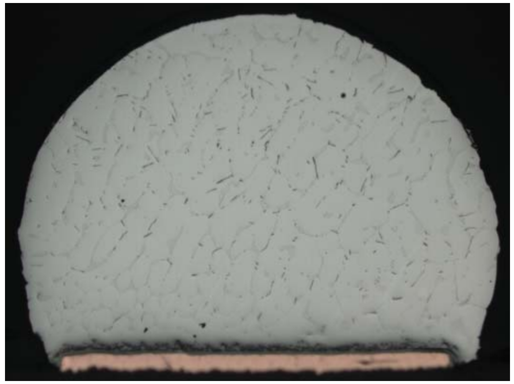


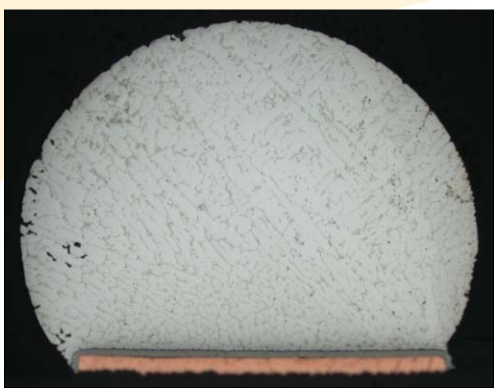
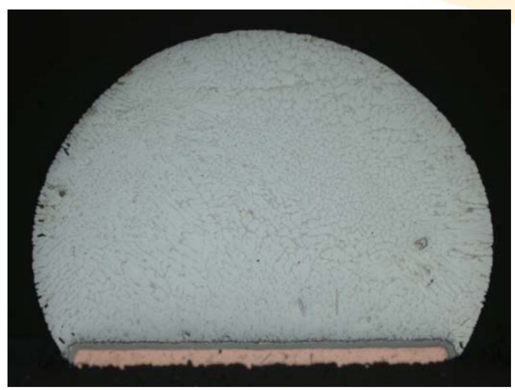
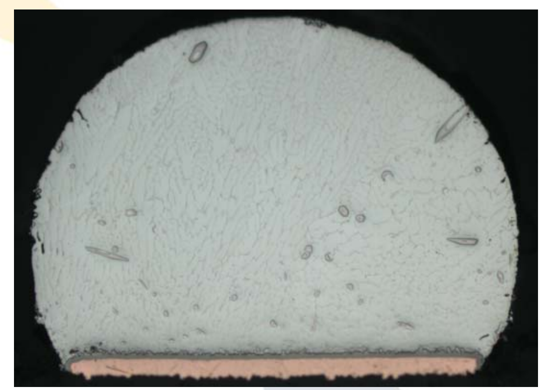
Surface image

	
Sn 1.0Ag – 0.45mm	**Sn 3.0Ag 0.5Cu – 0.45mm**

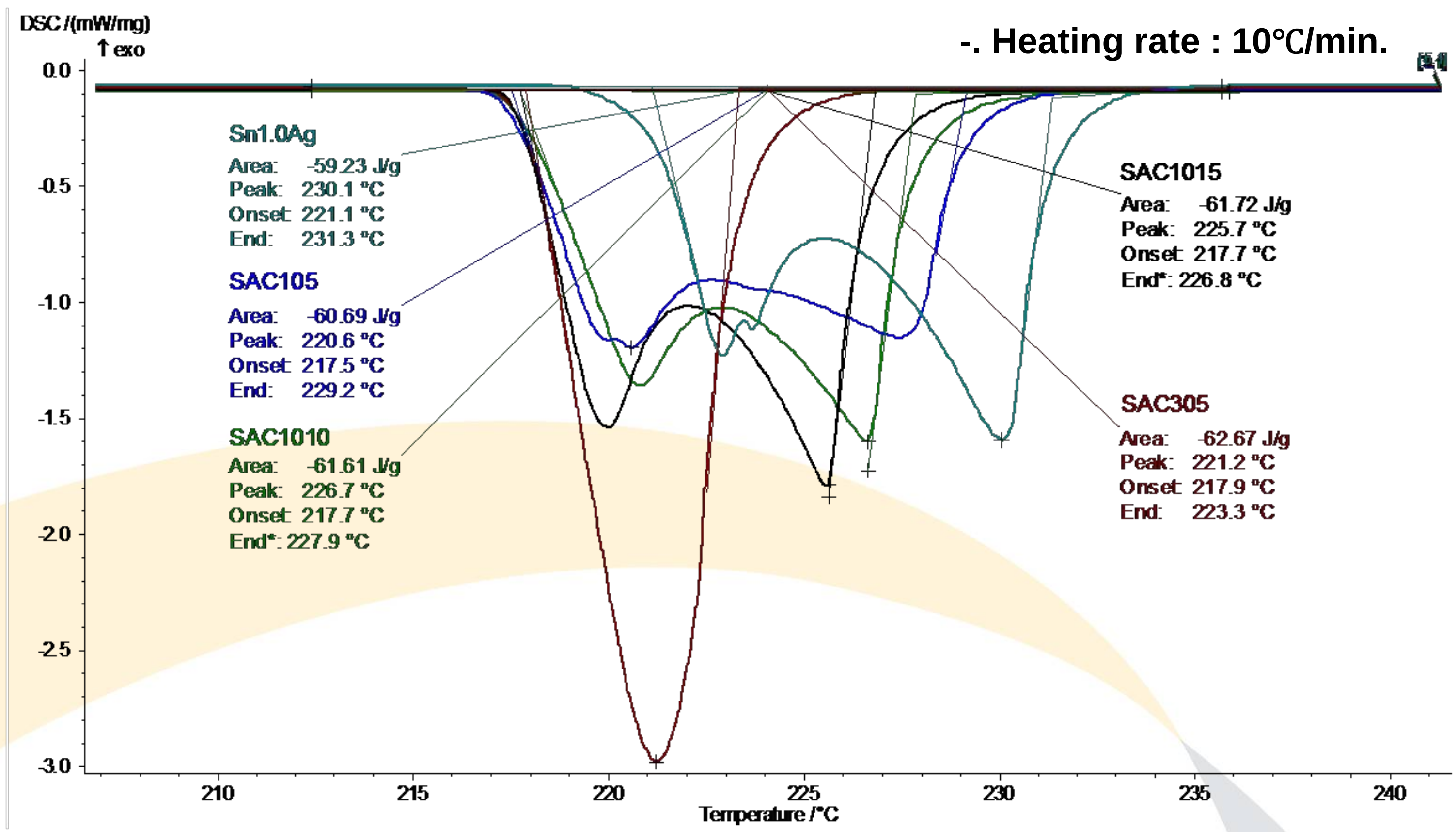
		
Sn 1.0Ag 0.5Cu – 0.45mm	**Sn 1.0Ag 1.0Cu – 0.45mm**	**Sn 1.0Ag 1.5Cu – 0.45mm**

Solder bump morphology

	
Sn 1.0Ag – 0.45mm	**Sn 3.0Ag 0.5Cu – 0.45mm**

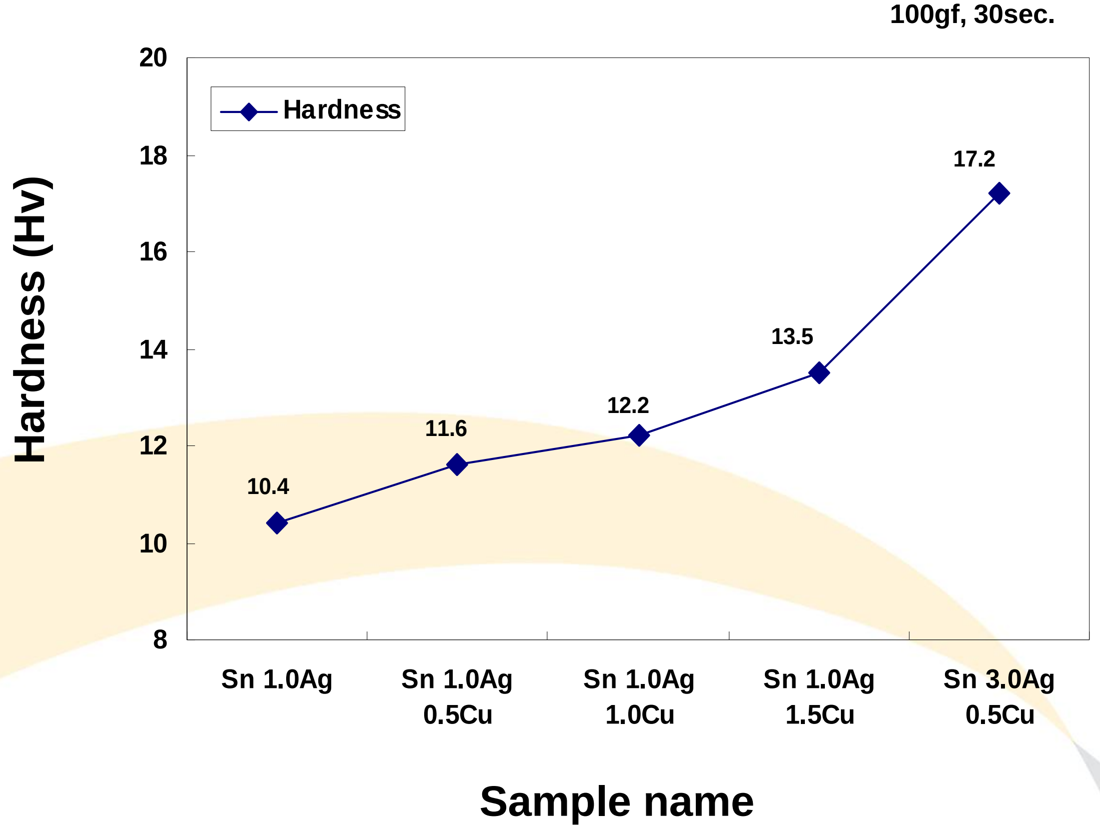
		
Sn 1.0Ag 0.5Cu – 0.45mm	**Sn 1.0Ag 1.0Cu – 0.45mm**	**Sn 1.0Ag 1.5Cu – 0.45mm**

DSC curve



	On set (℃)	End (℃)	Peak temp. (℃)	Melting range (℃)
Sn 1.0Ag	221.1	231.1	230.1	**221.1 ~ 231.1**
Sn 1.0Ag 0.5Cu	217.5	229.2	220.6	**217.5 ~ 229.2**
Sn 1.0Ag 1.0Cu	217.7	227.9	226.7	**217.7 ~ 227.9**
Sn 1.0Ag 1.5Cu	217.7	226.8	225.7	**217.7 ~ 226.8**
Sn 3.0Ag 0.5Cu	217.9	223.3	221.2	**217.9 ~ 223.3**

Hardness



-. Sn 3.0Ag 0.5Cu solder has more hardness than others.

-. In case of low Ag, the more Cu contents increase, the more hardness increases.

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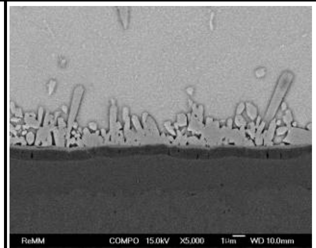
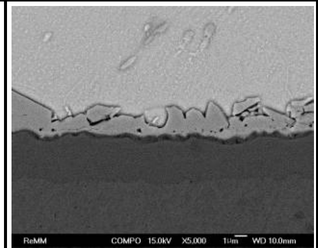
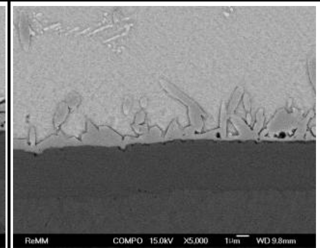
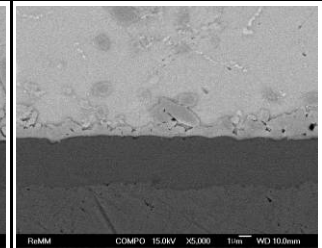
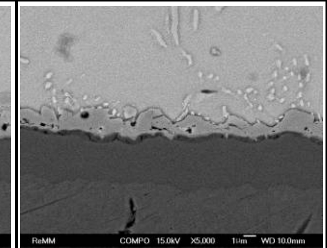
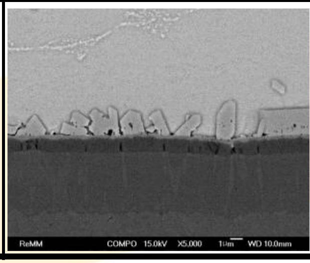
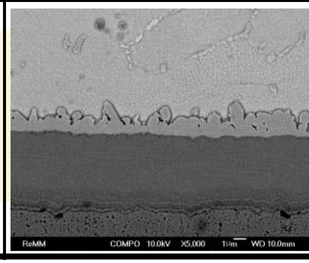
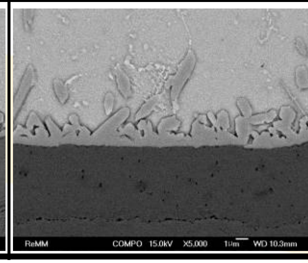
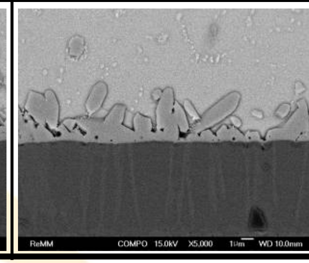
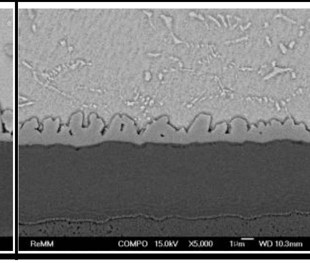
Inter-metallic compound

	Sn 1.0Ag	Sn 1.0Ag 0.5Cu	Sn 1.0Ag 1.0Cu	Sn 1.0Ag 1.5Cu	Sn 3.0Ag 0.5Cu
ENIG finished					
ENEPIG finished					

-. It shows the different IMC shape according to the combinations of various pad finished and solder compositions.

-. The Ni-P layer on ENEPIG finished shows more uniform shape than that of ENIG finished shows.

-. The inter-metallic compounds are composed of $(Cu,Ni)_6Sn_5$ and Ni_3Sn_4.

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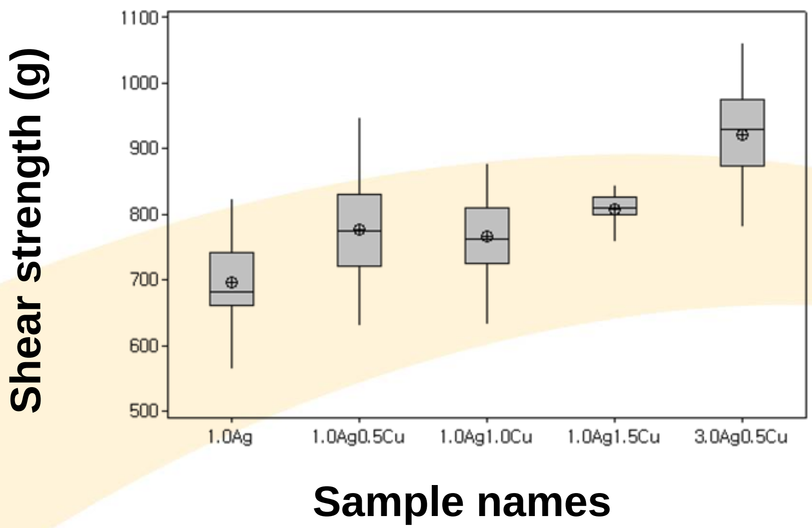
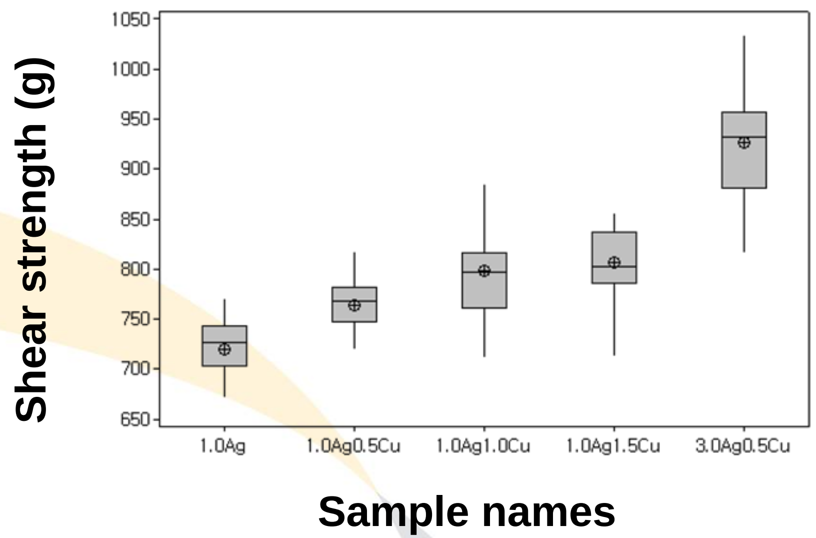
Ball shear strength

-. Test speed : 300㎛/s -. Shear height : 20㎛ -. Ball size : 0.45mm

ENIG pad



ENEPIG pad



-. Sn 3.0Ag 0.5Cu solder has more strength than others.

-. In case of low Ag, the more Cu contents increase, the more strength increases.

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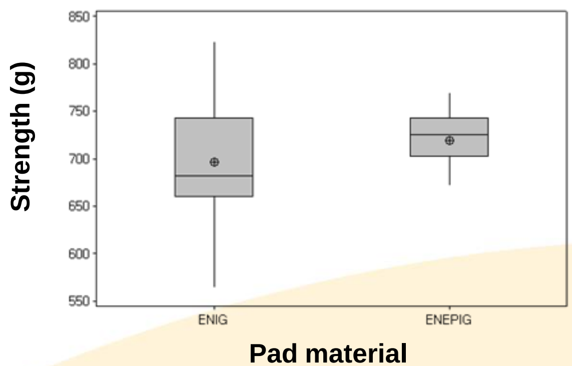
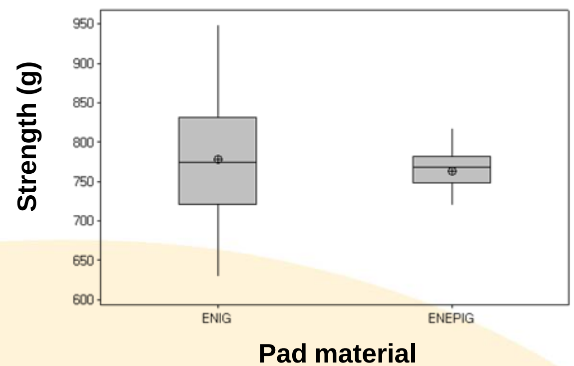
Ball shear strength

- **Comparison ENIG with ENEPIG.**

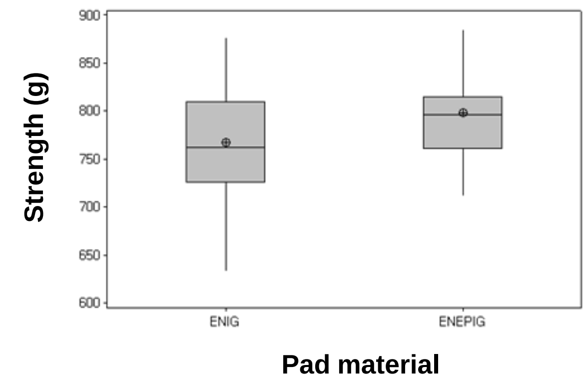
<Sn 1.0Ag>



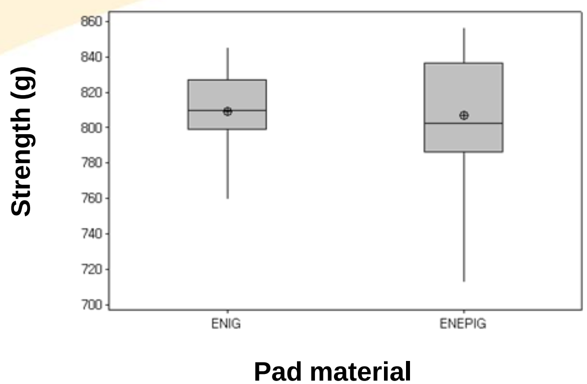
<Sn 1.0Ag 0.5Cu>



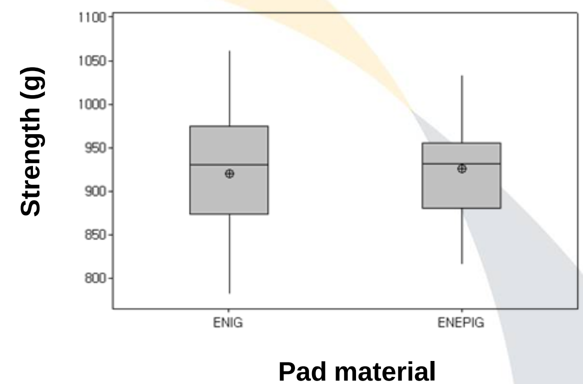
<Sn 1.0Ag 1.0Cu>



<Sn 1.0Ag 1.5Cu>



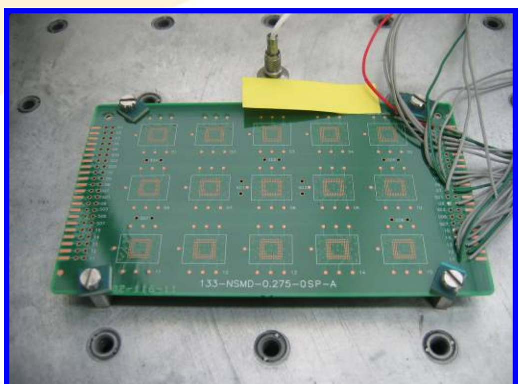
<Sn 3.0Ag 0.5Cu>



-. The shear strength has a similar regardless of pad finished.

High drop performance

Test machine



Drop Test Board

Test condition

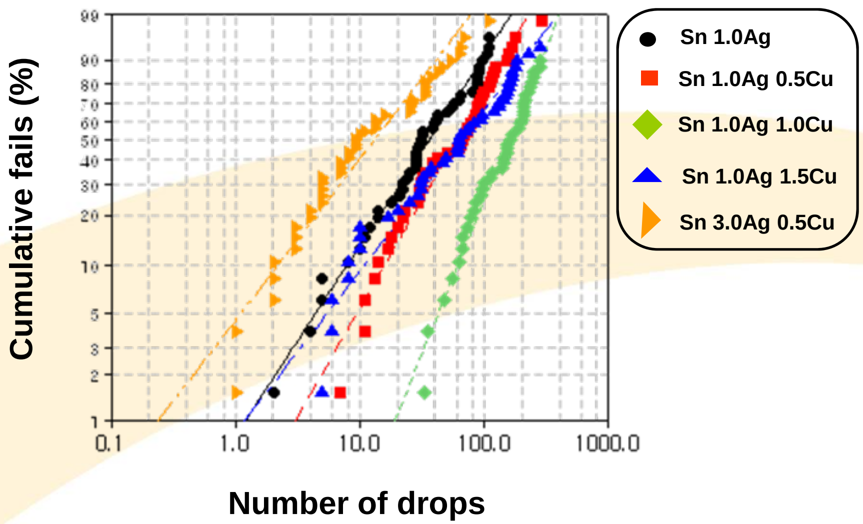
	Conditions			
Test Conditions	Machine	SD-10 (LAB)		
	Acceleration	1500 G		
	Count	300 times		
Packages	Package	Board	Unit No	15 units / Leg X 3
	ENIG, ENEPIG	OSP	45 units	
Solder Alloys	Sn 1.0Ag, Sn 1.0Ag 0.5Cu			
	Sn 1.0Ag 1.0Cu, Sn 1.0Ag 1.5Cu			
	Sn 3.0Ag 0.5Cu			

*** All samples have been assembled by DSHM std.**

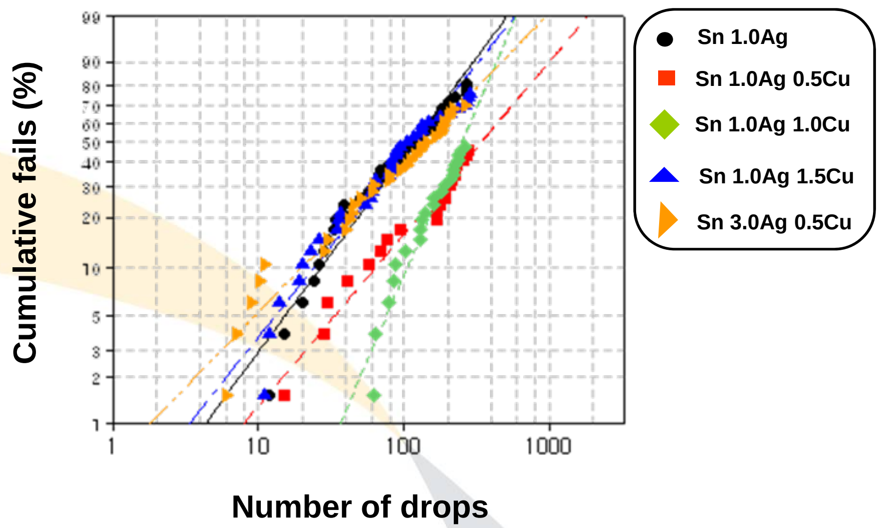
Weibull plot of test result

-. Drop shock failure result is analyzed by **Weibull method**.

ENIG pad



ENEPIG pad



-. Sn 1.0Ag 1.0Cu solder has the best drop performance.

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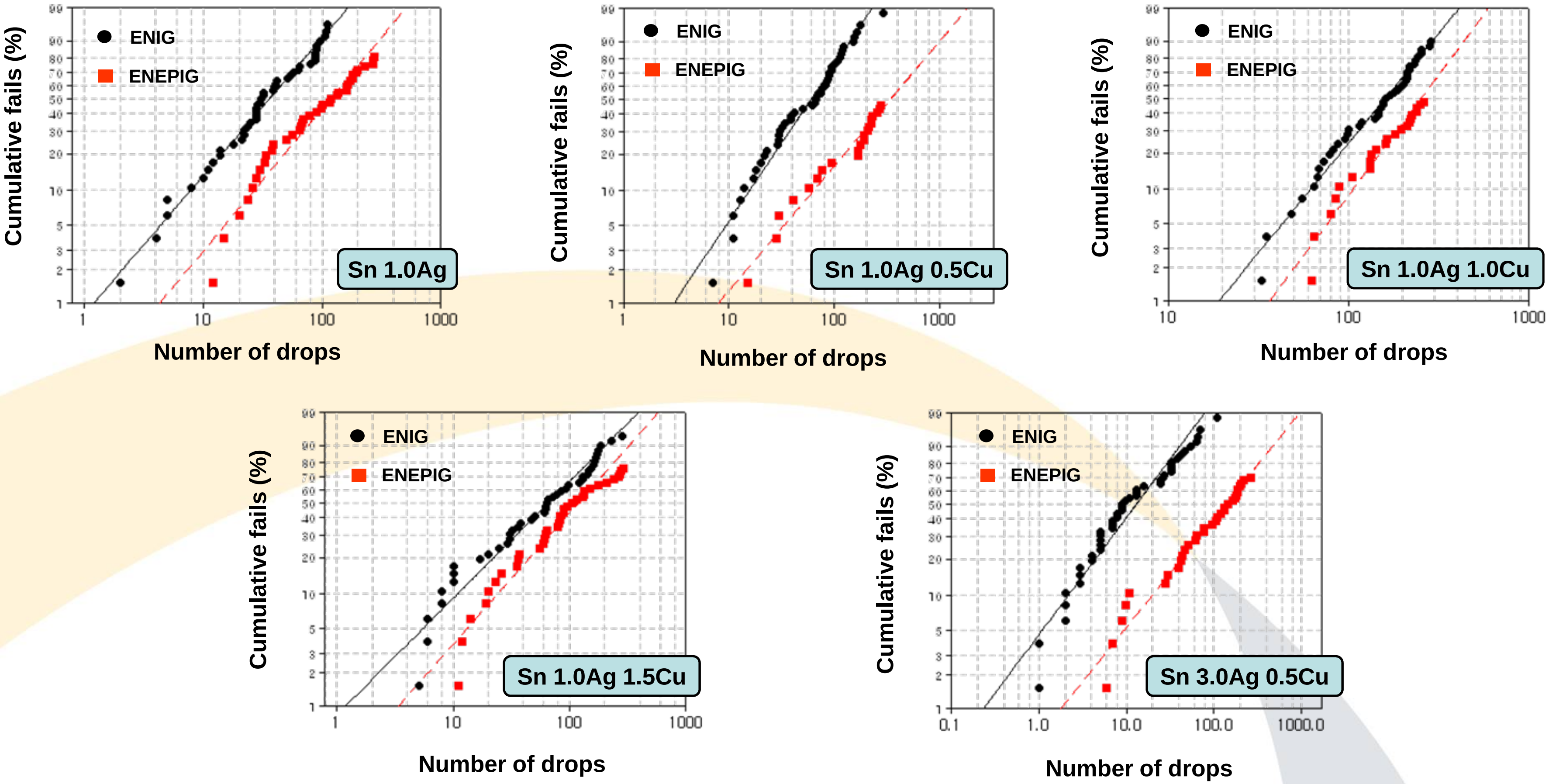
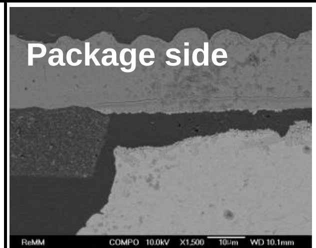
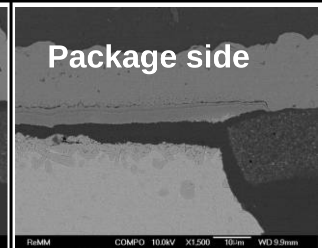
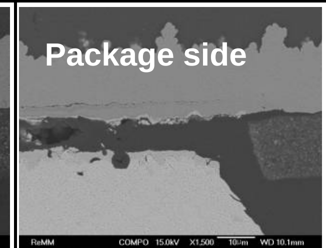
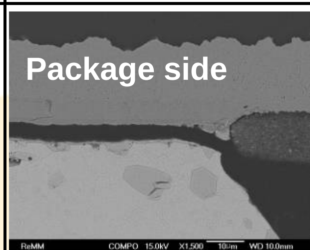
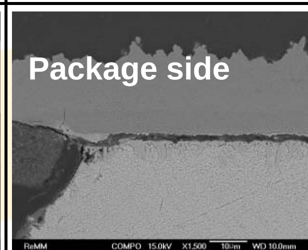
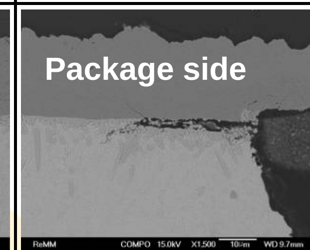
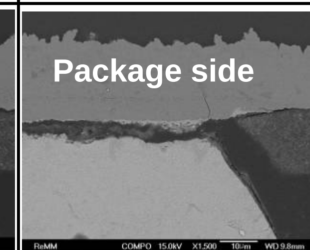
Weibull plot of test result

Comparison ENIG with ENEPIG.

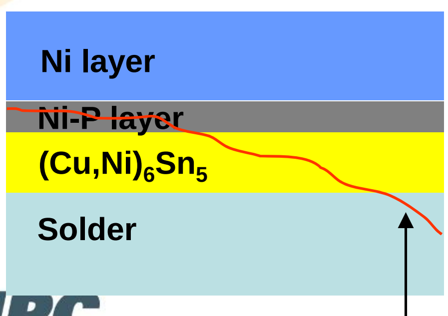


-. ENEPIG pad has better reliability than ENIG pad.

Fracture mode after drop strength

	Sn 1.0Ag	Sn 1.0Ag 0.5Cu	Sn 1.0Ag 1.0Cu	Sn 1.0Ag 1.5Cu	Sn 3.0Ag 0.5Cu
ENIG finished					
ENEPIG finished					

Schematic



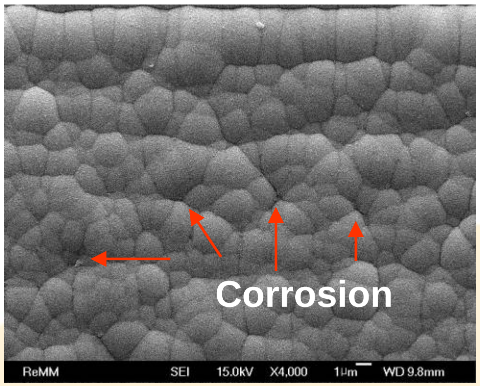
Crack

-. Crack propagates along with the P containing IMC on package side (Interfacial Fracture Mode)

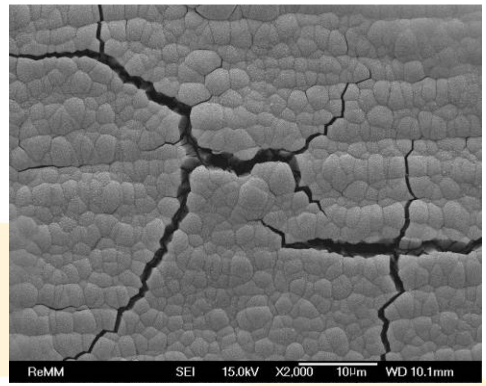
Analysis of mechanism

- **The reason why ENEPIG pad shows high drop performance than ENIG pad**

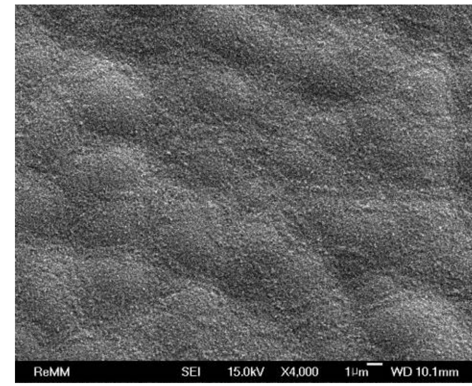
1. Gold layer was dissolved by a selective stripping solution.



<ENIG pad>



<ENIG pad>



<ENEPIG pad>

2. There were inter-granular corrosion dregs of Ni oxide in ENIG pad,

being caused by electric potential between Au and Ni.

<Chemical reaction equation → $Ni + 2Au^{-} = Ni^{2+} + 2Au$>

3. In case of ENEPIG pad, this surface was similar to that of ENIG pad

but, there was no corrosion under the ENEPIG pad.

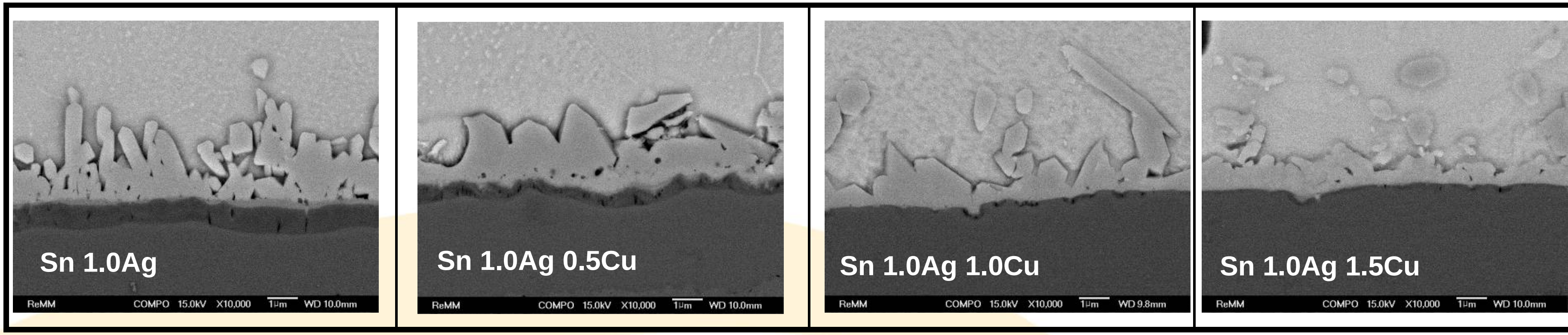
4. Ni-P layer on ENEPIG pad after reflow is thinner than that of ENIG pad.

Analysis of mechanism

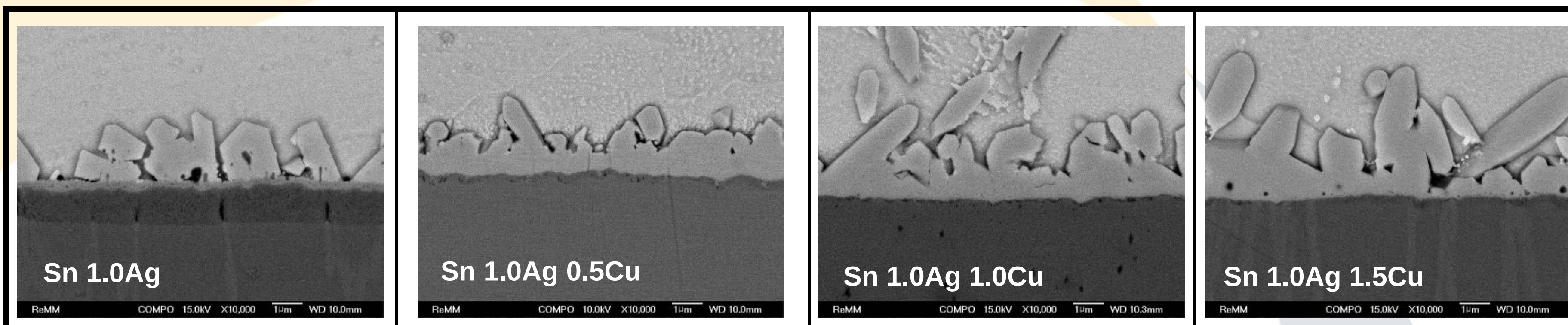
- **The reason why Sn 1.0Ag 1.0Cu shows high drop performance than others.**

1. Ni-P layer thickness according to Cu contents.

<ENIG pad>



<ENEPIG pad>



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Analysis of mechanism

- **The reason why Sn 1.0Ag 1.0Cu shows high drop performance than others.**

2. The more cu contents increase, the more Ni-P layer decreases.

3. Cu in solder delays the dissolution rate of Cu from boards to solder side And vice Versa.

4. Cu prevents Ni-P accumulation at the solder joint by fast Cu_6Sn_5 formation because less Ni participated in Cu-Ni-Sn IMCs formation.

5. High Cu contents more than 1.2wt% shows the negative influence to the reliability.

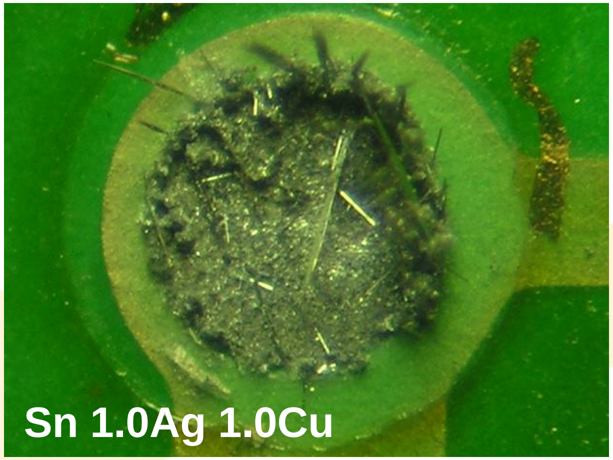
The Cu above the limited solubility caused to increase the precipitation Hardening.

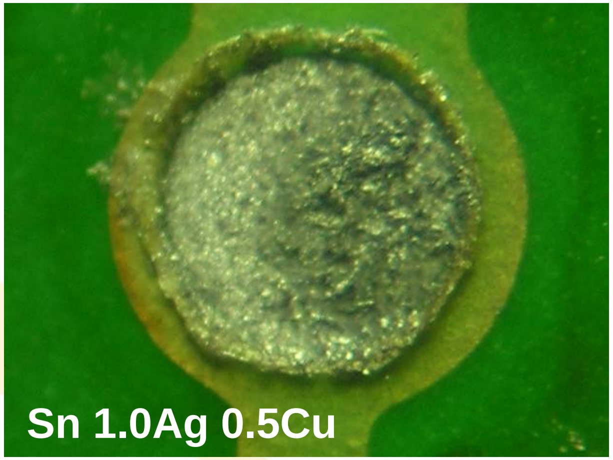
These behaviors in the ductile solder are interrupted to dissipate more energy during plastic deformation.

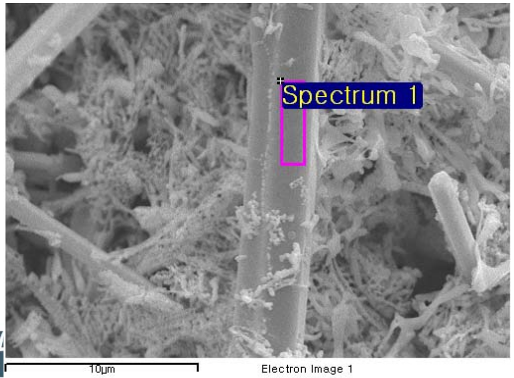
Analysis of mechanism

- **The reason why Sn 1.0Ag 1.0Cu shows high drop performance than others.**

<Top view photo after 6times reflow>







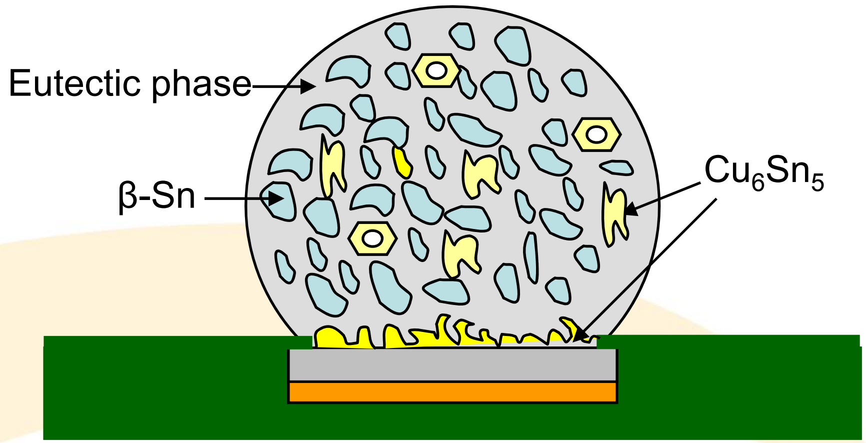
% of weight					
N	O	**Sn**	Ag	**Cu**	Ni
1.85	7.01	54.98	1.60	32.78	1.78

-. Rod type IMC is composed of $(Cu,Ni)_6Sn_5$.

Analysis of mechanism

- **The reason why Sn 1.0Ag 1.0Cu shows high drop performance than others.**

<Microstructure in solder : Sn 1.0Ag 1.0Cu>



-. Dispersed Cu accelerates nucleation site.

-. These behaviors make the fine grains and controls the IMC shapes & thickness even though Cu contents are high.

-. Fine grain and dispersed IMC(Cu_6Sn_5)s interrupt to dislocation behavior.

Effect of precipitation hardening.

-. Rod (needle) type IMCs interrupt to crack propagation.

Conclusion

1. It shows the different IMC shape according to the pad finished and solder composition.

2. The inter-metallic compounds are composed of $(Cu,Ni)_6Sn_5$ and Ni_3Sn_4.

3. The Ni-P layer on ENEPIG finished shows more uniformed shape than that of ENIG finished.

4. ENEPIG pad has better reliability than ENIG pad.

    4.1. There were inter-granular corrosion dregs of Ni oxide in ENIG pad,

    being caused by electric potential between Au and Ni.

    4.2. In case of ENEPIG pad, this surface was similar to that of ENIG pad

    but, there was no corrosion under the ENEPIG pad.

Conclusion

5. The reason why Sn 1.0Ag 1.0Cu shows high drop performance than others.

   5.1. Cu prevents Ni-P accumulation at the solder joint by fast Cu6Sn5 formation because less Ni participated in Cu-Ni-Sn IMCs formation.

   5.2. Effect of precipitation hardening.

6. High Cu contents above about 1.2wt% shows negative influence to the reliability.

   6.1. The Cu above the limited solubility caused to increase the precipitation Hardening.

   6.2. These behaviors in the ductile solder are interrupted to dissipate more energy during plastic deformation.

We need to control the Cu contents (from 1.0 to 1.2wt%) to increase the reliability.