A STUDY OF THE ENEPIG IMC FOR EUTECTIC AND LF SOLDERS

G.Milad, D.Gudeczauskas, G.Obrien, A.Gruenwald
Uyemura International Corporation
Southington, CT

ABSTRACT:
The solder joint formed on an ENEPIG surface with 4 different pastes namely eutectic Sn/Pb solder, copper doped Sn/Pb solder, SAC 305 and Sn/Ag were analyzed after thermal stress ageing. The nature of the IMC and its propagation were examined by SEM in cross section as well as top down view. The top down view was obtained by stripping the reflowed paste, so that the examination of variability in the IMC surface can be conducted.

The study shows that the SAC 305 and copper doped (1%) Sn/Pb make a very robust solder joint on the ENEPIG surface, when compared with eutectic Sn/Pb or Sn/Ag solder. The IMC is limited in thickness and more important limited in its propagation under extended thermal stress conditioning (500 hours at 150^{o}C).

EPMA analysis show that the copper is an integral part of the IMC and its presence allows for the Pd to be evenly distributed in the IMC. In contrast, in the absence of copper, there are distinct clusters of Pd,Ni/Sn segregated from the Ni/Sn forming the IMC.

The effect of palladium thickness on the integrity of the solder joint, when using SAC 305 solder, was also evaluated using a similar protocol. The data shows that increasing the palladium thickness will adversely impact the solder joint reliability.

KEY WORDS:
ENEPIG, IMC, Eutectic, LF solder

INTRODUCTION:
Surface finish products have been on the fast track of evolution to meet the complexity of newer designs (lighter, faster, smaller) as handheld devices like i-pods, smart-phones, PDAô s, digital cameras, camcorders, scanners etc. continue down the form factor path. The new challenge is RoHS compliance and the need to have lead-free finishes and more important lead-free assembly compatible finishes.

Surface finish is about connectivity. It is the surface which either protects or forms the connection from the board to a device. Today there is an impressive line up of surface finish products in use as Eutectic Sn/Pb HASL replacement. The list includes: ENIG (electroless nickel/immersion gold), ENEPIG (electroless nickel/ electroless palladium/immersion gold), immersion silver, immersion tin, OSP, as well as DIG (direct gold on copper).

ENEPIG (Electroless Nickel/Electroless Palladium/Immersion Gold) is formed by the deposition of electroless Ni (120 ï 240 εins) followed by 2 ï 6 εins of electroless Pd with an immersion gold flash (1 ï 2 εins). ENEPIG is a good soldering surface, a gold wire bondable surface, aluminum wire bondable surface, as well as a contacting surface.

Studies [1],[2] conducted to evaluate the reliability of the solder joint formed on an ENEPIG surface finish with LF solder and LF assembly conditions, were very eye opening.

Under the thermal stress conditions used in the study, the data showed that ENEPIG was unique in the fact that it formed a robust, higher strength solder joint with LF SAC 305 alloy, as compared to the solder joint formed with eutectic Sn/Pb solder.

In this study 1% copper doped Sn/Pb was added in an effort to explain why SAC 305 was superior to both Sn Ag and eutectic SnPb.

TEST PROTOCOL:
The test vehicle was a double sided 0.062ò FR-4 board. The board was copper plated, using commercially available acid copper and patterned see figures 1 and 2 . Solder mask was applied. The boards were then plated with ENEPIG surface finish. For this study the BGA pads were screened with the respective solder paste and reflowed.

Table 1 shows the process sequence, that the boards were subjected to, for the application of the ENEPIG surface finish. All chemicals used were commercially available products.

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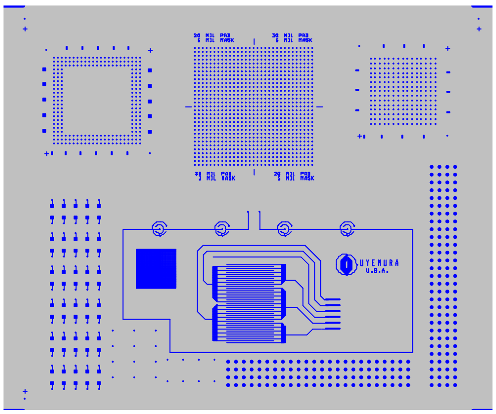


Fig 1: Top side of the Test Vehicle with the BGA pattern used in the center top

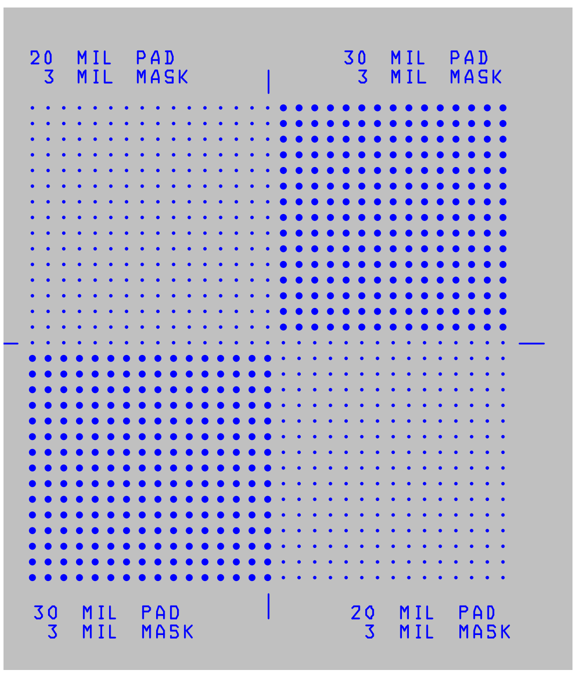


Fig 2: Close up of the BGA pattern used with details of pad sizes

The thickness of the deposited layers were verified using XRF measurements as specified below:
Pin diode XRF: ThermoNoran Micron X
Collimator used 20 mils in diameter
Measurement time 3 minutes per pad

Calibration: FP (fundamental parameters) used to create the calibration file with a verification using the following NIST traceable standards:

#1: 0.8µò Au/4µòPd/100µòNi
#2: 4µòAu/15µòPd/250µòNi

Table 1: Process Sequence
(Panels were dried using a horizontal conveyorized dryer).

Process step	**Product**	**Temp °C**	**Time min**
Soak Clean	ACL-007	50	5
Rinse		Ambient	1
Acid Dip	5% Sulfuric	Ambient	1
Rinse		Ambient	1
Micro-etch	SPS	Ambient	1
Rinse		Ambient	1
Pre-dip	5% Sulfuric	Ambient	1
Catalyst	MNK-4	30	2
Rinse		Ambient	1
Eòless Ni	NPR-4	80	25
D/O Rinse		Ambient	1
Rinse	DI water	Ambient	1
Eòless Pd	Talon 2.0	65	12
D/O Rinse		Ambient	1
Rinse	DI Water	Ambient	1
Im Gold	TAM-55	80	10
D/O Rinse		Ambient	1
Rinse	DI Water	Ambient	1

The average thickness values for Ni, Pd and Au obtained were as follows:

Nickel: 171 ε ins SD 11.1
Palladium: 7.2 ε ins SD 0.81
Gold: 1.2 ε ins SD 0.09

Solder details: All solder was Type 3, no clean flux ROL0

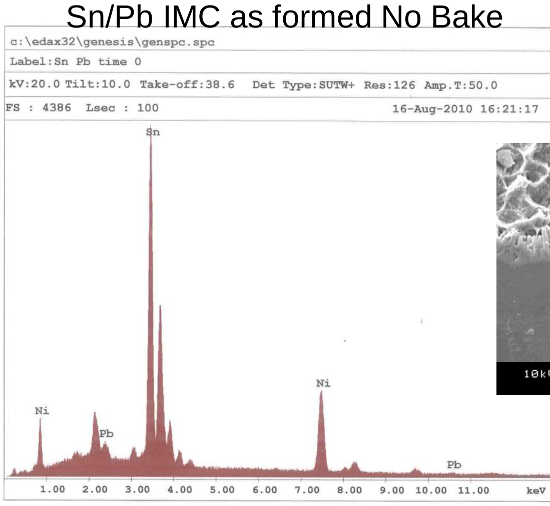
- SnPb: Indium Corp (mp 183°C)
- SnPbCu: Indium Corp Cu doped at 1%, (mp 187°C)
- SAC 305: Indium Corp (mp 217°C)
- SnAg 3.5: Alpha Metals (mp 212°C)

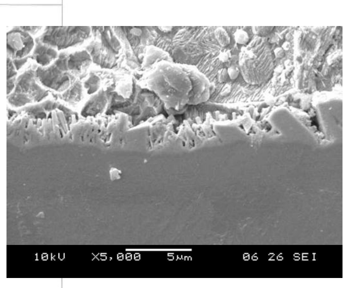
The solder paste was screened on the BGA pads and reflowed under the following conditions:

- SnPb and Cu doped SnPb solder, were reflowed at 225°C, with 60 seconds above liquidus
- LF SAC 305 and SnAg (3.5) were reflowed at 247°C with 70 seconds above liquidus.

The samples were then cross section to examine the IMC as formed. The parts were then subjected to thermal

Sn/Pb IMC as formed No Bake



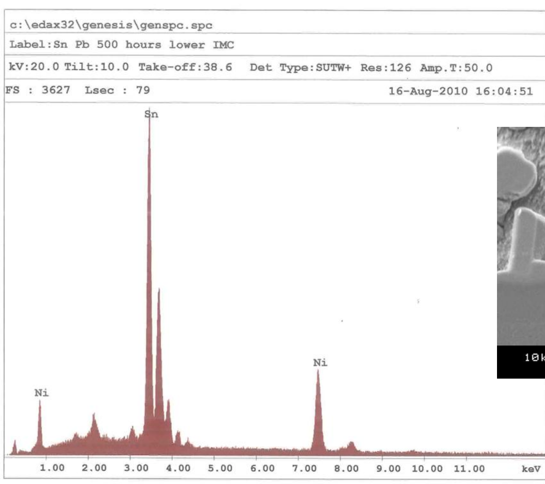


EDAX ZAF Quantification (Standardless)
Element Normalized
SEC Table : Default

Element	Wt %	At %	K-Ratio	Z	A	F
SnL	68.80	54.28	0.6425	0.9536	0.9762	1.0032
NiK	27.66	44.12	0.2931	1.1297	0.9368	1.0011
PbL	3.53	1.60	0.0289	0.8213	0.9956	1.0000
Total	100.00	100.00				

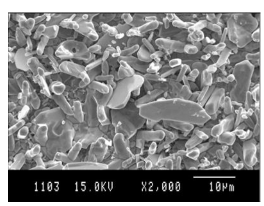
Element Net Inte Bkgd Inte Inte Error P/B

Sn/Pb IMC after 500 hours bake at 150^{o}C



EDAX ZAF Quantification (Standardless)
Element Normalized
SEC Table : Default

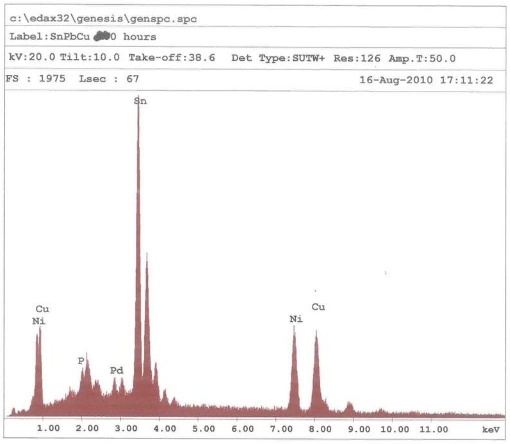
Element	Wt %	At %	K-Ratio	Z	A	F
SnL	71.28	55.10	0.6753	0.9504	0.9935	1.0034
NiK	28.72	44.90	0.3028	1.1246	0.9374	1.0000
Total	100.00	100.00				

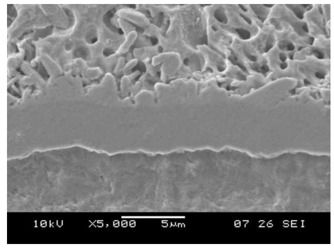


Top view after solder strip

Figure 3 Sn/Pb before and after bake

Sn/Pb/Cu IMC as formed No Bake

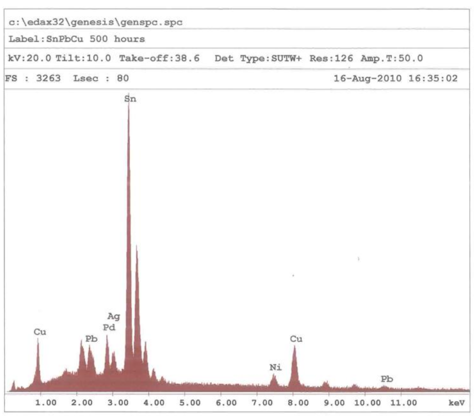


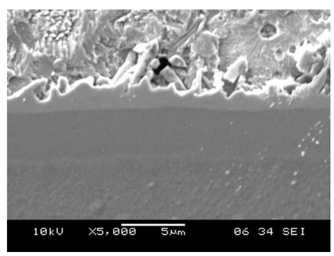


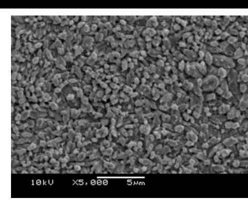
EDAX ZAF Quantification (Standardless)
Element Normalized
SEC Table : Default

Element	Wt %	At %	K-Ratio	Z	A	F
P K	1.84	4.75	0.0118	1.1689	0.5417	1.0071
PdL	3.06	2.30	0.0269	0.9567	0.8963	1.0234
SnL	49.02	32.96	0.4426	0.9317	0.9668	1.0026
NiK	20.46	27.82	0.2143	1.0983	0.9534	1.0000
CuK	25.61	32.17	0.2592	1.0494	0.9643	1.0000
Total	100.00	100.00				

Sn/Pb/Cu IMC after 500 Hr bake at 150°C







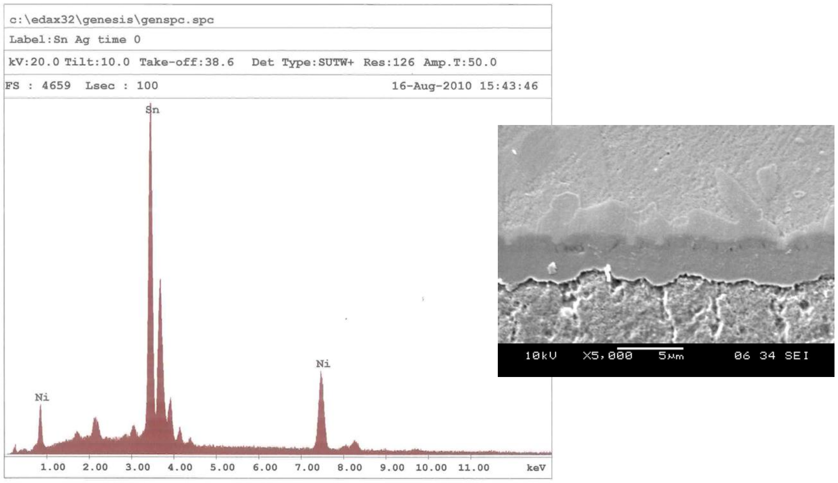
Top view after solder strip

EDAX ZAF Quantification (Standardless)
Element Normalized
SEC Table : Default

Element	Wt %	At %	K-Ratio	Z	A	F
PdL	7.42	7.23	0.0657	1.0055	0.8596	1.0244
AgL	0.47	0.45	0.0043	1.0121	0.8887	1.0226
SnL	60.86	53.15	0.5384	0.9762	0.9060	1.0004
NiK	3.71	6.55	0.0402	1.1603	0.9317	1.0034
CuK	16.67	27.19	0.1761	1.1103	0.9466	1.0050
PbL	10.87	5.44	0.0918	0.8474	0.9966	1.0000
Total	100.00	100.00				

Figure 4 Sn/Pb/Cu before and after bake

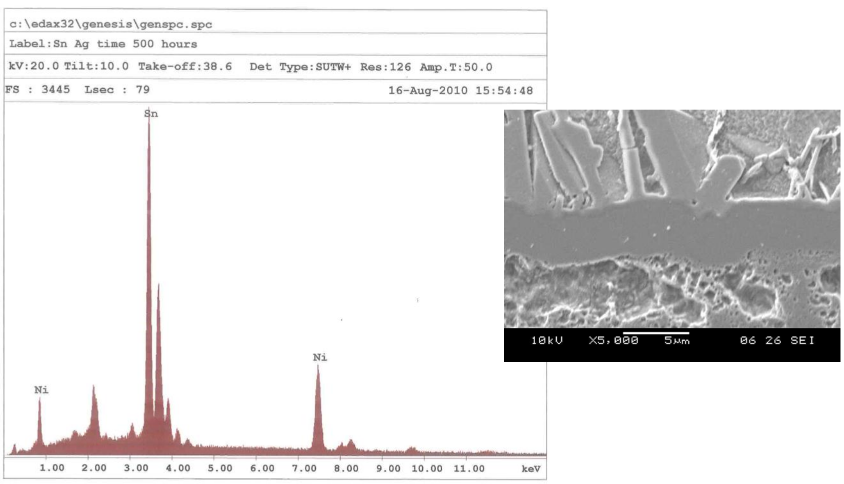
Sn/Ag IMC as formed No Bake



EDAX ZAF Quantification (Standardless)
Element Normalized
SEC Table : Default

Element	Wt %	At %	K-Ratio	Z	A	F
SnL	73.38	57.69	0.6979	0.9537	0.9940	1.0031
NiK	26.62	42.31	0.2812	1.1291	0.9356	1.0000
Total	100.00	100.00				

Sn/Ag IMC after 500 Hours bake at 150^oC

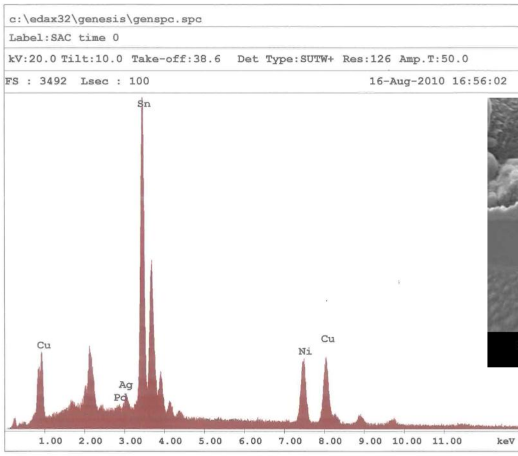


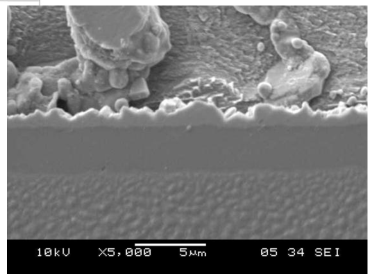
EDAX ZAF Quantification (Standardless)
Element Normalized
SEC Table : Default

Element	Wt %	At %	K-Ratio	Z	A	F
SnL	70.50	54.18	0.6671	0.9491	0.9933	1.0035
NiK	29.50	45.82	0.3107	1.1230	0.9381	1.0000
Total	100.00	100.00				

Figure 5 Sn/Ag (3.5) before and after bake

SAC 305 IMC as formed No bake

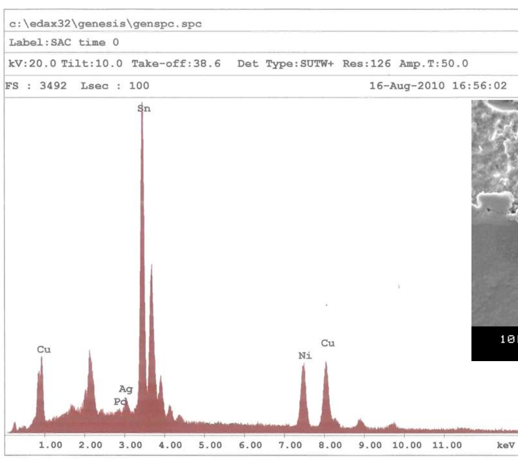


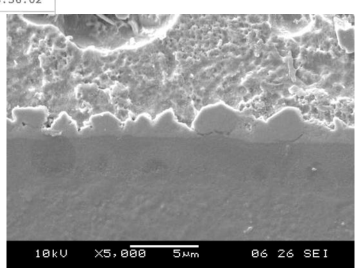


EDAX ZAF Quantification (Standardless)
Element Normalized
SEC Table : Default

Element	Wt %	At %	K-Ratio	Z	A	F
PdL	1.55	1.24	0.0139	0.9677	0.9027	1.0277
AgL	0.58	0.46	0.0054	0.9749	0.9283	1.0257
SnL	56.31	40.48	0.5189	0.9418	0.9762	1.0023
NiK	18.21	26.47	0.1920	1.1118	0.9479	1.0000
CuK	23.35	31.35	0.2381	1.0626	0.9598	1.0000
Total	100.00	100.00				

SAC 305 IMC as formed No bake





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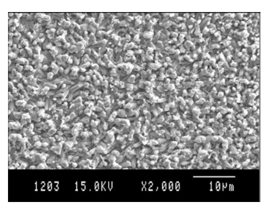
Total	100.00	100.00				



Top view after solder strip

Figure 6 SAC 305 before and after bake conditioning/baking for an extended duration. Cross sections were taken and the IMC was examined after the thermal bake/conditioning.

The parts were conditioned in a ñPrecisionò isotemp oven for 500 hours at 150^oC. A 36 gauge welded tip K type thermocouple was soldered to a pad on a PCB of similar size that was also a 2 layer. The temperature recorded in the solder joint controlled the conditioning temperature rather than the oven set point. The temperature was controlled to +/- 2 ^oC. The oven was returned to room temperature before removing the samples to avoid any rapid cool down that might have a negative impact on the solder structure.

Figures 3,4,5 & 6 below show EDX elemental analysis and SEM at 5000X for the 4 types of solder before and after heat stress. Also included are the top down views of the IMC after solder stripping for Eutectic Sn/Pb, SAC 305 and copper doped eutectic solder.

All samples were micro-etched before SEM-EDX using a 1% nitric acid in methanol solution.

The before bake samples showed excellent wetting and a relatively thin IMC that was consistent with the refow time at temperature. The eutectic Sn/Pb solder exhibited a certain degree of lack of thickness uniformity, while the SAC305, Sn/Pb/Cu and SnAg exhibited a relatively even (uniform thickness) IMC. See figures.

After incubation (thermal conditioning):

- SnPb IMC grew in thickness (~5X) and was very uneven,
- SnPbCu IMC show very limited propagation (~1.5 X) and was relatively even.
- SAC305 IMC showed very limited propagation and was very even
- SnAg IMC grew in thickness as much as the eutectic Sn/Pb and was very uneven.

The SnPb, SAC 305 and SnAg solders performance confirmed previously reported observation. What is new in this study is the observation for the SnPbCu. The data shows that copper doped eutectic solder SnPbCu behaved very similar to SAC 305 and gave a very robust solder joint form shear strength values and limited propagation as well as evenness of the IMC.

The incubated SnPb, Sn/Pb/Cu and SAC305 reflow samples were then solder stripped and the morphology of the IMC was examined. The contrast was very obvious (see figures above). There was a dramatic difference between the morphology of the IMC of the SnPb sample as compared to the copper bearing samples. The copper bearing samples showed a relatively fine grained morphology, while the SnPb was coarse grained and formed clusters.

The data suggests that the copper in the solder plays a significant role in preserving the integrity of the solder joint. Previously reported EPMA analysis results showed that the Cu is concentrated in the intermetallic IMC layer and allows the Pd to dissipate evenly into the IMC forming $(Cu,Ni)_6Sn_5$+Pd. The EDX analysis in this study confirms that copper is an integral part of the IMC

In absence of Cu, SnPb and SnAg solders do not exhibit this homogenous IMC, but show segregated clusters of $(Pd,Ni)_3Sn_4$. These clusters allow the IMC under thermal stress to propagate and remain uneven; resulting in a weaker solder joint.

Now that the study has established that copper bearing LF solder makes a superior solder joint than eutectic Sn/Pb solder, the question then becomes: is there a thickness limit as to how much palladium can dissipate into the IMC? Another study was completed to determine if increasing the palladium layer thickness would have any adverse effects on the integrity of the solder joint.

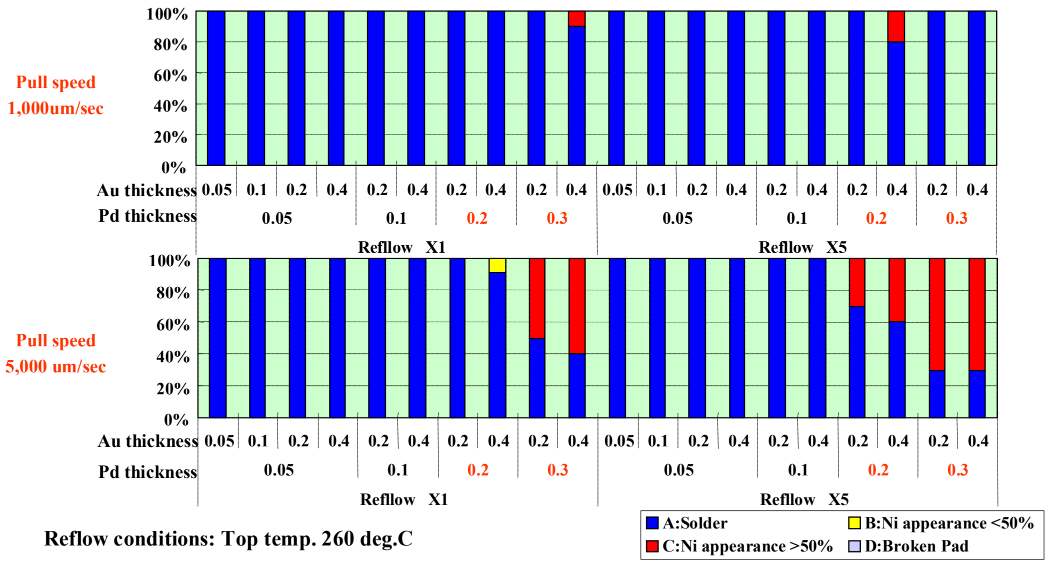
In this study; BGA substrates were plated with palladium thickness varying from 2 uins to 12 uins, and the gold thickness was varied from 2 εins to 16 εins, while the nickel thickness remained constant at 200 εins. SAC 305 solder balls were attached to the BGA substrate. The samples were split into 2 groups. One group was conditioned using 1X LF reflow (260^oC) and the second was conditioned at 5X LF reflow. The balls were then pulled at 2 different speeds namely 1000 εm/sec and at 5000 εm/sec. The fracture interface was then examined. The results are graphed and tabulated in Figure 7..

The 1000 εm/sec pull speed did not exhibit any significant difference in fracture mode; all samples fractured within the solder ball. The 5000 εm/sec pull speed differentiated the thickness combinations as they related to fracture mode. Two distinct fracture modes were recorded; a fracture within the solder ball and an interfacial fracture that showed >50% nickel.

In the higher speed pull, both the 1X reflow and the 5X reflow exhibited interfacial fractures. At 1X reflow approximately 50% of the balls attached to the 12 εins thick palladium showed interfacial fractures. At 5X reflow approximately 35% of the balls attached to 8 εins palladium and ~70% of the balls attached to 12 uins of palladium showed interfacial fractures.

The variation in gold thickness was not a contributor to the interfacial fracture under the conditions of testing.

Figure 7 Fracture Mode for SAC305 Ball Pull results
Effect of Au and Pd thickness



The Pd thickness should be below 0.2um for optimum solder joint reliabilities.

CONCLUSION:
In the first test using ENEPIG as the surface finish, it was demonstrated that the presence of copper in SAC305 plays a significant role in increasing the solder joint reliability. The copper dissipates the palladium evenly in the IMC and does not allow for excessive propagation of the IMC when conditioned at 150^{o}C for 500 hours. The addition or doping of eutectic SnPb solder with 1% copper demonstrated the same enhanced reliability.

The combination of ENEPIG with Sn/Pb eutectic solder is not recommended for high temperature use environments.

In the second test SAC305 solder balls were attached to BGA substrates plated with varying thicknesses of palladium and gold over a fixed nickel thickness. The samples were stressed at 1x and 5X reflow thermal cycles. The fracture mode of the ball pull testing indicated that palladium thickness should be less than, < 8 εins for maximum solder joint reliability.

REFERENCES:
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UYEMURA Corporate Headquarters:
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