IMC Growth Study on Ni-P/Pd/Au Film and Ni-P/Au Film Using Sn/Ag/Cu Lead Free Solder

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Abstract
The surface finishes Ni-P/Pd/Au (hereafter referred to ENEPIG) and Ni-P/Au (hereafter referred to ENIG) were prepared on ball grid array (BGA) circuit boards by electroless/immersion plating method. The IMCs (Inter metallic compounds) of Sn37Pb and Sn3.0Ag0.5Cu solder with these finishes were compared using TEM (Transmission Electron Microscope). It was found that the IMC crystal lattice is dependant on solder material and the solder joint reliability is dependant on both the solder material as well as the surface finish. In using Sn3.0Ag0.5Cu solder, the Pd in the ENEPIG finish limits the Ni diffusion and exhibits excellent solder joint reliability. In the combination of Sn/Pb solder and ENEPIG, the Ni diffusion is accelerated and solder joint reliably is compromised.

Introduction
Electroless Ni-P/Au plating (hereafter referred to ENIG) has been widely used as electronic devices and IC packaging. A solder ball mounting method, which is one of the mounting methods, is required to have higher solder joint reliability as solder joint pads become smaller and industry moves to a lead free environment.

In addition, the lead-free solder mounting method requires higher reflow temperatures than conventional methods in solder mounting, thus lowering the solder joint reliability. It was found that the deposition of an electroless palladium layer between electroless nickel and immersion gold plating (hereafter referred to ENEPIG) insures an excellent solder joint even with higher reflow temperatures and thermal histories. In this paper, we present a comparative study of the solder joint characteristics and IMCs with combinations of surface treatments (ENIG, ENEPIG) and solder materials (Sn/37Pb, Sn/3.0Ag/0.5Cu) using TEM and EPMA analytical techniques.

Experimental and Results
Preparation Method of Comparative Samples with ENIG and ENEPIG deposited films.
Sample substrates for evaluation were prepared as follows: after acid copper plating on a copper-clad laminate (FR4) BGA pads of 0.6 mm diameter were formed using solder resist (solder mask defined) with and Ni-7%P/Au (ENIG) (5µm/0.05µm) and Ni-7%P/Pd/Au (ENEPIG) (5µm/0.06µm/0.03µm) metallization.

Evaluation Method of Solder Joint and Results
On the various sample substrates, solder balls of Sn/37Pb and Sn/3.0Ag/0.5Cu were mounted, followed by heat treatment at 150^{o}C in air for 0, 100, 300, 500, and 1000 hours. After heat treatment ball pull tests were conducted. The conditions of ball pull testing are shown in Table 1, and the results of ball pull tests are shown in Figure 1 (in the case of Sn/Pb solder) and Figure 2 (in the case of Sn/Ag/Cu solder).

Table 1. Ball pull test conditions

Solder ball:	
Pad diameter:	
Flux:	
Reflow machine:	
Ball pull:	
Ball pull speed:	

はんだボール	0.76mmφ Sn-37Pb Solder（Senjyu)
	0.76mmφ Sn-3.0Ag-0.5Cu Solder（Senjyu)
パット径	0.6mmφ
フラックス	529D-1 RMA type(Senjyu)
リフロー装置	TMR-15-22LH(Tamura)
ボールプル装置	Dage 4000
ボールプル速度	170μm/sec.

*Reflow temperature: peak temperature of 240°C

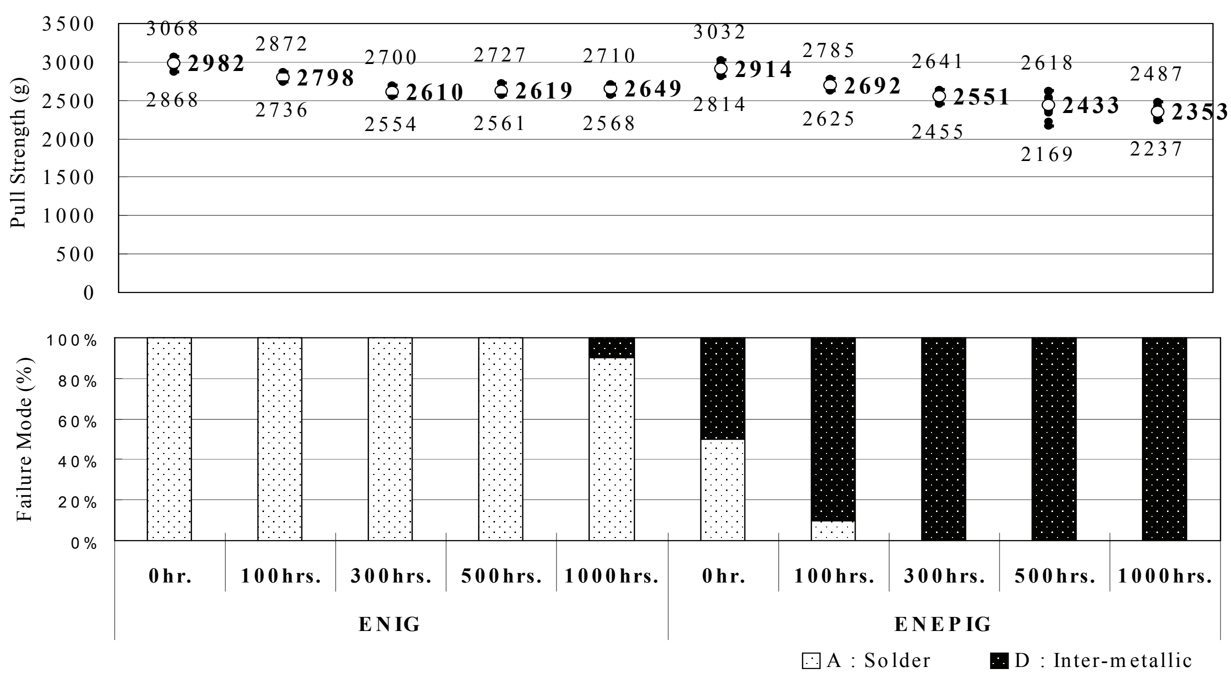


Figure 1 - Results of Ball Pull Test when Sn/37Pb was Used

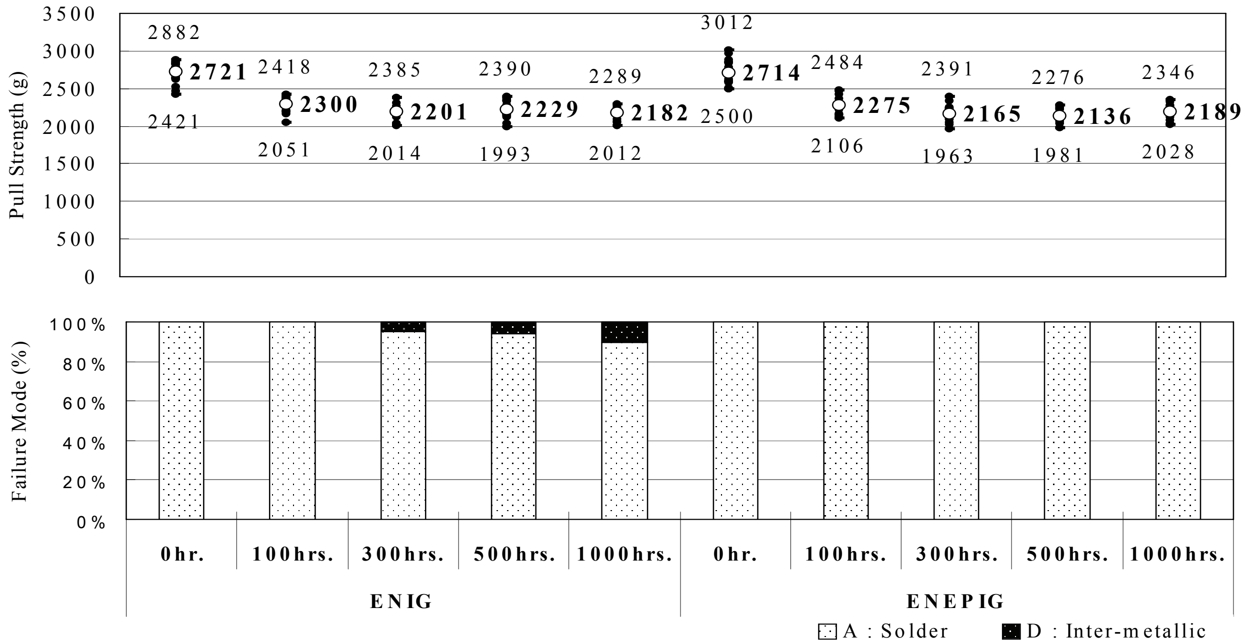


Figure 2 - Results of Ball Pull Test when Sn/3.0Ag/0.5Cu was Used

As shown in Figure 1, in the case of Sn/Pb solder, the change of failure mode, which indicates a change of the joint interface, showed no clear difference when ENIG film was used. However, the change in failure mode was remarkable when ENEPIG was used. Whereas with the ENIG all failures occurred in the bulk solder even with thermal aging, with ENEPIG failures were predominantly in the IMC with the percent of IMC failures increasing rapidly with thermal aging.

As shown in Figure 2, when Sn/Ag/Cu solder was used some change of failure mode was observed in the case of ENIG film, but no change of failure mode was observed in the case of ENEPIG film This is the desired characteristic.

On the other hand, from the fact that the pull strength is similar in all the conditions, it is probable that all the changes in performance are due to the recrystallization of solder materials.

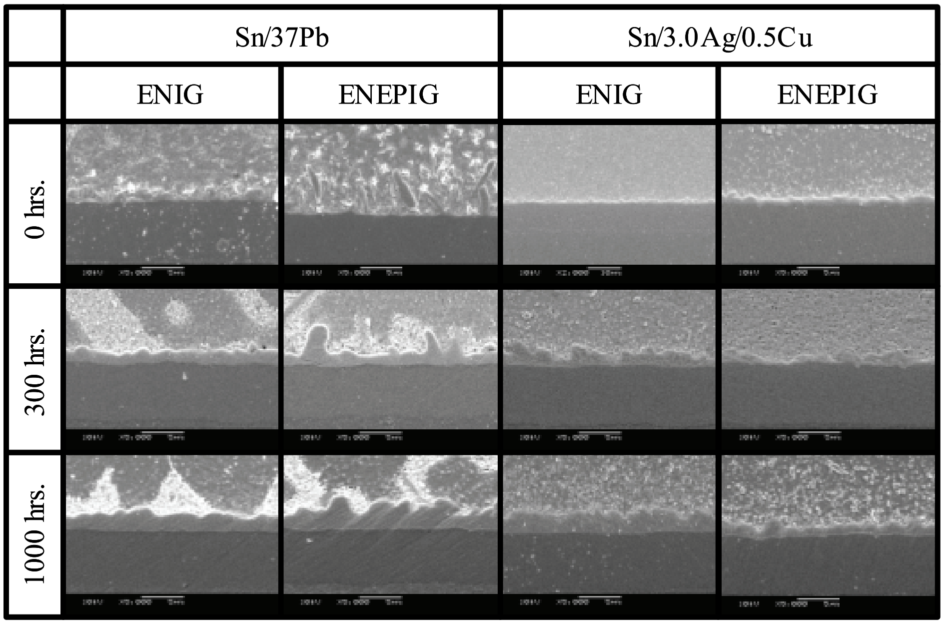


Figure 3 - SEM Photographs of IMC

Results of SEM Observation of IMC

Figure 3 shows SEM photographs in the sectional observation of the samples heat-treated for 0, 300, and 1000 hours after each solder mounting. Figure 3 confirms that the IMC of ENEPIG deposited film with Sn/Pb solder caused the remarkable change of failure mode in the pull test. The IMC layer is thick while the IMC of ENEPIG deposited film with Sn/Ag/Cu solder is thin. Note that the change in failure mode from bulk solder to the IMC layer (for the Sn/PB-ENEPIG combination) corresponds to the thickening of the IMC layer. This would indicate that the diffusion rate of nickel depends on the combination of plating film composition and solder material.

Confirmation of Each Elemental Distribution on Joint Boundary Face by EPMA

Mapping results by EPMA for each element on the joint interface in the samples heat-treated at 150^{o}C-1000 hours after solder mounting on ENEPIG film is shown in Figures 4 and 5. Figure 4 shows the results in the case of Sn/Pb solder, and Figure 5 in the case of Sn/Ag/Cu solder. As shown in Figure 4, it is obvious that the Pd and Pb are clearly isolated from each other in Sn/Pb solder. In contrast, the Pd is distributed uniformly in the IMC layer in the case of Sn/Ag/Cu solder as is shown in Figure 5.

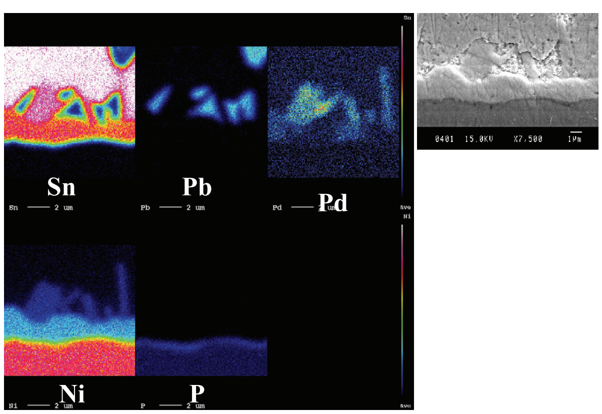


Figure 4 - EPMA Analysis of Joint Boundary Face

Sn/Pb solder with ENEPIG film

(150 degree C-1000 hours heat treatment)

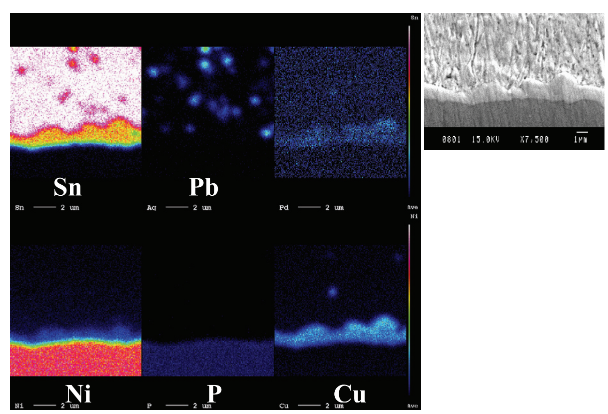


Figure 5 - EPMA Analysis of Joint Boundary Face

Sn/Ag/Cu solder with ENEPIG film

(150 degree C-1000 hours heat treatment)

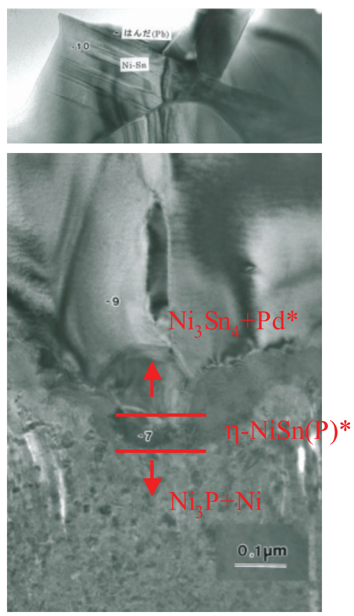
Analysis of Metal Alloy Layer by TEM

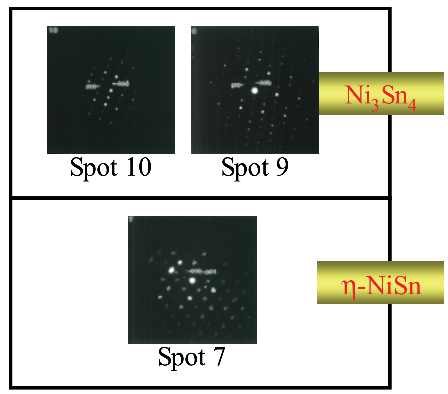
In order to determine the IMC composition in the samples heat-treated for 1000 hours after Sn/Pb or Sn/Ag/Cu solder mounting on ENEPIG film, the samples were prepared by a FIB method and observed using Transmission Electron

Microscopy (TEM, a JEM-2010F manufactured by JEOL Ltd., Japan).

Figure 6 shows the TEM pictures, electron probe analysis, and EDS results for the sample prepared with Sn/Pb solder. As shown in Figure 6, there are areas where Pd is detected and not detected, and both areas show the crystal lattice of $NiSn_4$, which was identified by comparing with JCPDS card files. From this fact, we confirmed that Pd does not enter the crystal lattice, but forms two kinds of IMC layers, namely a layer denoted as ($NiSn_4$ + Pd) and a layer denoted as η-NiSn(P). In the case where Sn/Ag/Cu solder was used (shown in Fig. 7), we confirmed that Pd, in the same way as in Sn/Pb solder, does not enter the crystal lattice, but forms two IMC layers, namely η-$(Cu,Ni)_6Sn_5$ + Pd, and η-NiSnP.

Moreover, performing the same test using Sn/Pb and Sn/Ag/Cu solders on ENIG film, we confirmed that the results are consistent with those in the literature. [1]



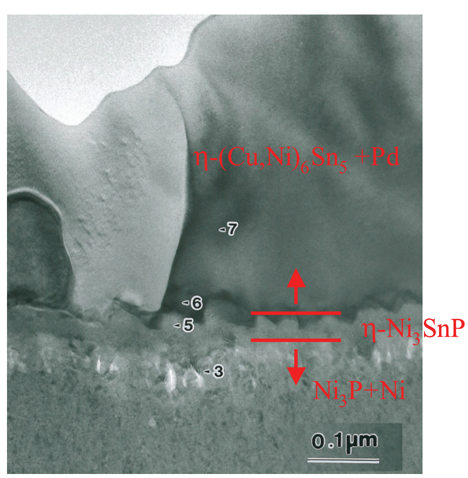


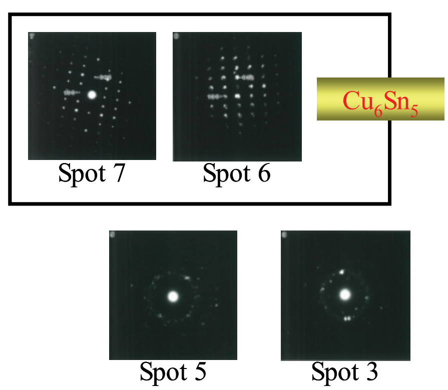
Quantitative analysis result (EDS)

		at%					
	Spot	P	Ni	Cu	Pd	Sn	Pb
Sn/37Pb	10	0.0	18.9	0.4	2.4	78.3	0.0
	9	0.2	35.6	1.4	0.0	62.8	0.0
	7	5.5	47.8	0.7	0.4	45.5	0.1

* Not determination representation

Figure 6 - TEM Data for a Sample Heat-Treated at 150°C-1000 hr After Mounting Sn/Pb Solder on ENEPIG





Quantitative analysis result (EDS)

		at%					
	Spot	P	Ni	Cu	Pd	Ag	Sn
Sn/3Ag/0.5Cu	7	0.1	17.2	35.1	1.1	0.1	46.4
	6	0.0	18.9	33.2	0.6	0.1	47.3
	5	18.0	64.2	0.1	0.0	0.0	16.8
	3	28.7	68.7	0.4	0.0	0.1	2.1

Figure 7 - TEM data for a Sample Heat-Treated at 150°C-1000 hr After Mounting Sn/Ag/Cu Solder on ENEPIG

Conclusion

In the case where a Sn/Ag/Cu solder joint is formed on ENEPIG film, it is thought that IMC of η-$(Cu,Ni)_6Sn_5$ + Pd is formed, so Pd delays the diffusion of nickel into solder. This would explain why the IMC thickness is thin compared to that in the ENIG film. We conclude that this is the cause of the excellent solder joint characteristics shown. On the other hand, in the case where Sn/Pb solder joint is formed on the ENEPIG film, we conclude that the isolation of Pb and Pd on the joint interface causes the diffusion of nickel to accelerate, resulting in the thick IMC and deterioration of solder joint.

References

(1) Chi-Won Hwang, Katsusaki Suganuma. J.Mater. Res., **18,**2540, Nov (2003)