CHARACTERISTICS OF EPIG DEPOSITS FOR FINE LINE APPLICATIONS

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ABSTRACT
The ability to plate fine patterns, solder joint reliability (SJR) and the wire bonding reliability (WBR) of the electroless Pd/Au (EPIG) deposit were evaluated, along with the electroless Ni-P/Pd/Au (ENEPIG) deposit. SJR was evaluated using the high speed shear test (HSS) when comparing Sn-3.0Ag-0.5Cu with Sn-1.2Ag-0.5Cu-0.05Ni as the composition of the solder ball.

When using Sn-1.2Ag0.5Cu-0.05Ni as the solder ball for EPIG film, a uniform alloy layer was formed and SJR was excellent. EPIG deposits with thicker Pd had good WBR because the Pd layer prevented Cu diffusion to the top of the Au surface following heat treatment. And when the gold of the EPIG deposit was thicker, WBR improved because the ratio of Pd on the top surface was kept lower after heat treatment. On the other hand, WBR after heat treatment was improved by applying plasma treatment to the Au surface.

INTRODUCTION
In recent years, electronic devices such as smart phones and tablets have been miniaturized. The CSP (chip size package) inside the electronic devices has also been miniaturized, and wiring line spacing has narrowed. Some newer packages have wiring line spacing at 15 um or less.

In these instances, if electroless Ni-P (EN) film is 5-6um as is the case with conventional ENEPIG, the space of the wiring line will be 5um or less. This creates a risk of a short circuit between wiring lines. To prevent this, a thin EN process or EN-free process (EPIG) is recommended. With thin EN or EPIG, plating process times are short.

CSPs have mainly two kinds of EPIG processes that are ideal for high frequency devices and are a solution as well for the Ni allergy problem. CSPs involve primarily two joining methods with the substrate or IC chip: wire bonding between the IC chip and the package, and some type of solder joint. Therefore, it's necessary that the EPIG process focus on SJR, WBR and the pattern ability.

In this paper, we studied these characteristics of EPIG deposits, and compared them with ENEPIG deposits.

EXPERIMENTAL AND RESULTS
The coupons used in this study consisted of a copper-clad laminated substrate which was copper plated to a thickness of 20 µm using an acid copper electroplating process. For SJR tests, the copper-plated substrate was coated with solder mask and imaged to form 0.25mm diameter solder ball pads.

The substrate of the copper pattern with 15um wiring line spacing was used to evaluate pattern ability. Each substrate was plated with EPIG and ENEPIG using plating chemicals commercially available from C. Uyemura & Co., Ltd.

Table 1 shows the EPIG plating process.
Table 2 shows the ENEPIG plating process.

Table 1. EPIG plating process

Process	Chemical	Temp.	Time
Cleaner	Mild alkaline	50 degC	5 min
Soft etching	15g/L mono per.	30 degC	2 min
Acid rinse	10% Sulfuric acid	R.T.	1 min
Pre-dipping	0.4% Sulfuric acid	R.T.	1 min
Activator	Palladium-type	30 degC	1.5 min
Post-dip	acidic type	50 degC	0.5 min
Electroless Pd	Pd-P	60 degC	5 min (0.05um)
			10 min (0.10um)
			20 min (0.20um)
Electroless Au	Mixed reaction	78 degC	6 min (0.05um)

The target thicknesses were Pd = 0.05, 0.1, 0.2 µm and Au = 0.05, 0.1, 0.2, 0.3 µm

Table 2 ENEPIG plating process

Process	Chemical	Temp.	Time
Cleaner	Mild alkaline	50 degC	5 min
Soft etching	100g/L SPS	25 degC	1 min
Acid rinse	10% Sulfuric acid	R.T.	1 min
Pre-dipping	3% Sulfuric acid	R.T.	1 min
Activator	Palladium-type	30 degC	2 min
Electroless Ni-P	Mid phos Ni-P	80 degC	30 min
Electroless Pd	Pd-P	50 degC	5 min (0.05um)
			10 min (0.10um)
			20 min (0.20um)
			30 min (0.30um)
Electroless Au	Mixed reaction	78 degC	12 min

The target thicknesses were Ni = 6 µm, Pd = 0.1 µm and Au = 0.05, 0.1, 0.2, 0.3 µm

As the solder ball for the evaluation of SJR, 0.3 mm Φ of Sn-3.0Ag-0.5Cu (M705) 0.3 mm Φ of Sn-1.2Ag-0.5Cu0.05Ni (LF35) was used. The reflow profile with a peak temperature of 260 degrees C was applied for mounting the solder ball, as shown in Fig.1. SJR was measured by HSS test (Dage 4000HS / Dage) as shown in Table 3.

Heat treatment (HIGHTEMP OVEN PHH-101 / ESPEC) for 300 hours at 150 degrees C. followed mounting of the solder ball. The cross section image of IMC after mounting the solder ball was observed by FE-SEM (Ultra55 / Carl Zeiss) after polishing by cross section polisher (CP) (SM09010 / JEOL). The intermetallic (IMC) layer was analyzed by EDS (AXS / Bruker).

Table 3. HSS test conditions

Reflow equipment	Tamura TMR-15-22LH
Solder ball	SAC305 (M705) Sn-1.2Ag-0.5Cu-Ni (LF35)
Solder diameter	0.30mmφ
Pad size	0.25mmφ
Flux	529D-1
Reflow conditions	260 deg.C, 1 times
HSS test equipment	4000HS (Dage)

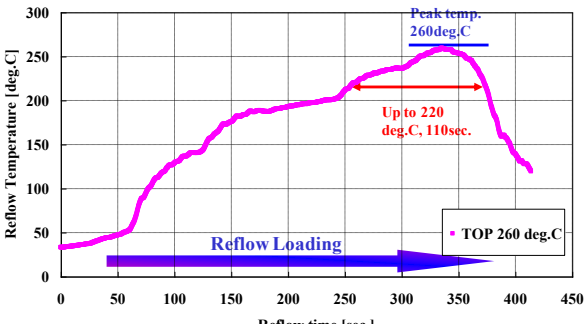


Figure 1. Reflow profile

WBR was evaluated by wire bonding (HB16 / TPT) and pull test (Dage 4000 / Dage) as shown in Fig. 2. Heat treatment for WBR was 16 hours at 175 degrees C.

Equipment	TPT HB16 (semi-auto)
Capillary	B1014-51-18-12 (PECO)
Wire	1.0mils gold
Temp.	150deg.C
Step	0.7mm
1st bonding conditions	Ultra sonic=250mW Time=200msec Force=25g
2nd bonding conditions	Ultra sonic=250mW Time=50msec Force=50g
Pull test equipment	Dage #4000
Pull speed	170um/sec

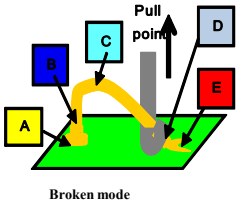


Figure 2. Wire bonding conditions

The element analysis for each film was measured by Auger electron spectroscopy (AES) (9500F / JEOL). The condition of AES is shown in Table 4.

Table 4. AES conditions

Wide scan		Depth profile	
Ep	: 10keV	Ep	: 10keV
Ip	: 4×10^-8A	Ip	: 4×10^-9A
Area	: 120*120(µm2)	Area	: 120*120(µm2)
Tilting Angle	: 30°	Tilting Angle	: 30°
		Aperture size	: 4

The plasma test after heat treatment was performed by plasma cleaner (PC-1100 / SAMCO). The condition of the plasma treatment was shown in Table 5.

Table 5. Plasma conditions

Process gas	: Ar
Flow rate	: 30sccm
Power	: 500W
Time	: 1min

PATTERN ABILITY FOR EPIG DEPOSITS

Fig. 3 shows the comparison of pattern ability between the ENEPIG and EPIG processes when using a substrate with 15um of wiring line spacing.

Although the ENEPIG process had over-plating in the space of the wiring line, no over-plating was observed for the EPIG process.

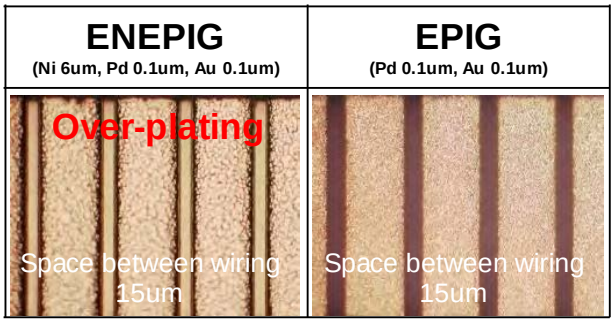


Figure 3. Over-plating of EPIG and ENEPIG

SOLDER JOINT RELIABILITY

For the EPIG and ENEPIG processes, SJR with the film as-plated and with heat treatment after mounting the solder ball (300hrs HT) were evaluated by HSS test as shown in Fig.4.

In this figure, M705 was used as the solder ball. The influence of Pd thickness was not confirmed within 0.05 to 0.2um. When comparing the as-plated film, the broken energies of ENEPIG film were better than that of EPIG. The broken energy of the EPIG film following heat treatment diminished, compared with the as-plated sample.

Conversely, with the ENEPIG process, the broken energy of HSS was maintained even if heat treatment was applied.

The cross section image of the IMC was observed in order to identify the cause of the HSS results. When using EPIG or ENEPIG film with Pd thickness of 0.1um and with Au thickness of 0.1um, the observation of IMC and the analysis of IMC composition by EDS is shown in Fig. 5. From the results of EDS, when using EPIG film, Cu_6Sn_5 was formed as layer 1 and Cu_3Sn was formed near the Cu layer as layer 2.

When using the ENEPIG film, (Cu, Ni)6Sn5 was formed as layer 1 and Ni+Ni3P was formed near the Ni-P layer as layer 2 [2) 3) 4)]. It was considered that the HSS results for ENEPIG were better as-plated because layer 1 of the ENEPIG film was more uniform than that of the EPIG film.

When comparing the film of 300hrs HT, layer 2 of EPIG thickened significantly because Sn was supplied from the solder phase by heat treatment. Layer 1 thickened as well. It was considered that these thicker IMC will cause poor broken energy of HSS.

On the other hand, the thickness of layer 1 and 2 was unchanged for the ENEPIG film. It was considered that Ni +Ni_3P was thinner as layer 2 because (Cu, $Ni)_6Sn_5$ was formed by the Cu in the solder ball of M705 and this IMC inhibited the growth of layer 2. Because layer 1 will gradually dissolve into the solder phase, thinner layer 1 was kept [1)]. Therefore, the broken energies of ENEPIG film were superior even with heat treatment.

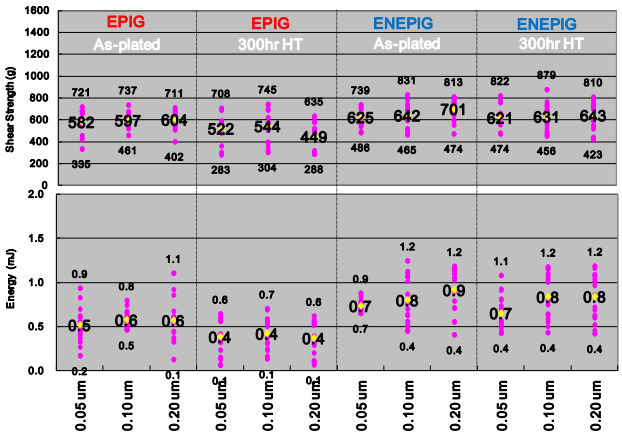


Figure 4. HSS results with M705 as the solder ball; EPIG (Pd 0.05-0.2um, Au 0.1um) and ENEPIG (Ni-P 6um, Pd 0.05-0.2um, Au 0.1um)

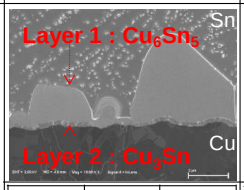
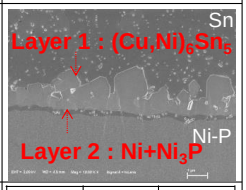
M705	EPIG			ENEPIG		
As-plated						
		Layer 1	Layer 2		Layer 1	Layer 2
	Ni	0.0	0.0	Ni	21.1	74.7
	P	0.0	0.0	P	1.3	17.0
	Cu	53.1	62.7	Cu	38.7	4.3
	Pd	0.0	0.0	Pd	0.2	0.3
	Sn	46.9	37.3	Sn	38.7	3.5

Figure 5. IMC observation and analysis of IMC composition by EDS with M705; EPIG (Pd 0.1um, Au 0.1um) and ENEPIG (Ni-P 6um, Pd 0.1um, Au 0.1um) as plated.

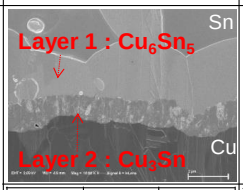
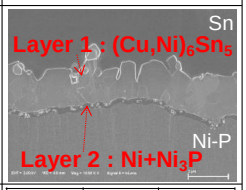
M705	EPIG			ENEPIG		
300 hours						
		Layer 1	Layer 2		Layer 1	Layer 2
	Ni	0.0	0.0	Ni	17.2	68.7
	P	0.0	0.0	P	0.1	28.7
	Cu	56.1	77.2	Cu	35.1	0.4
	Pd	0.0	0.0	Pd	0.6	0.0
	Sn	43.9	22.8	Sn	47.3	2.1

Figure 6. IMC observation and analysis of IMC composition by EDS with M705; EPIG (Pd 0.1um, Au 0.1um and ENEPIG (Ni-P 6um, Pd 0.1um, Au 0.1um after heat treatment

When using LF35 as the solder ball, the result of HSS is shown in Fig. 7. The observation of IMC and the analysis of IMC composition by EDS is shown in Fig. 8 and Fig. 9.

The broken energy of the HSS for the EPIG film was better, compared with the result for M705. From the results of EDS shown in Fig. 7, $(Cu,Ni)_6Sn_5$ was formed as layer 1 and Cu_3Sn was formed as layer 2. Ni was supplied for the solder ball of LF35. It was considered that layer 1 became uniform and thinner because its Ni inhibited its growth. A thinner and more uniform layer 1 will result in better broken energy in the HSS.

Layer 1 thickened following heat treatment, but layer 2 was unchanged. It was considered that $(Cu, Ni)_6Sn_5$ inhibited the growth of layer 2 by slowing the absorption of Sn into layer 2. As the result of IMC formation, the broken energy of 300hrs HT was worse than that of the as-plated EPIG film.

The HSS result for ENEPIG film was similar to that of M705 for both the as-plated and 300hrs HT sample - perhaps because similar IMC was formed even if a different solder ball was used. It appears possible that the SJR of the EPIG film was significantly improved by using LF35 as the solder ball. It is also possible that SJR can worsen with long term heat treatment. It's important to confirm the impact of prolonged heat treatment.

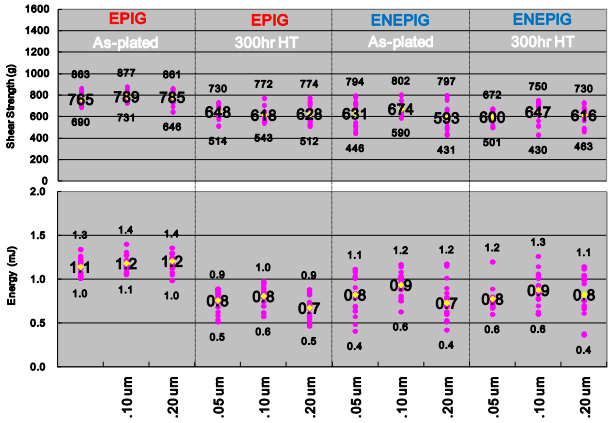


Figure 7. HSS result with LF35as the solder ball; EPIG (Pd 0.05-0.2um, Au 0.1um) and ENEPIG (Ni-P 6um, Pd 0.05-0.2um, Au 0.1um)

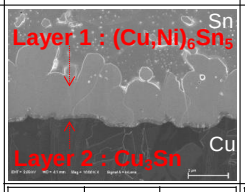
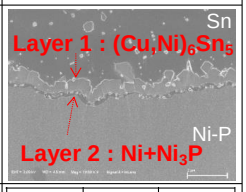
LF35	EPIG			ENEPIG		
As-plated						
		Layer 1	Layer 2		Layer 1	Layer 2
	Ni	5.3	0.4	Ni	33.2	75.7
	P	0.0	0.0	P	1.2	18.3
	Cu	54.6	77.7	Cu	30.7	3.6
	Pd	0.0	0.0	Pd	0.3	0.2
	Sn	40.1	21.9	Sn	34.6	2.2

Figure 8. IMC observation and analysis of IMC composition by EDS with LF35; EPIG (Pd 0.1um, Au 0.1um) and ENEPIG (Ni-P 6um, Pd 0.1um, Au 0.1um) as plated

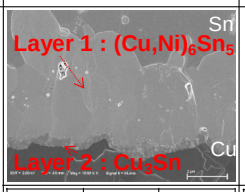
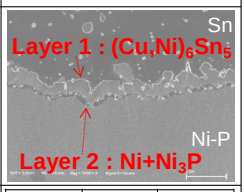
LF35	EPIG			ENEPIG		
300 hours						
		Layer 1	Layer 2		Layer 1	Layer 2
	Ni	6.6	0.1	Ni	20.2	66.5
	P	0.0	0.0	P	0.1	24.3
	Cu	52.4	75.5	Cu	32.8	0.5
	Pd	0.0	0.0	Pd	0.5	0.1
	Sn	40.4	24.4	Sn	46.4	8.6

Figure 9. IMC observation and analysis of IMC composition by EDS with LF35; EPIG (Pd 0.1um, Au 0.1um and ENEPIG (Ni-P 6um, Pd 0.1um, Au 0.1um after heat treatment

GOLD WIRE BONDING

The strength and failure mode of wire pull tests for as-plated samples of EPIG and ENEPIG films are shown in Fig. 10 and Fig. 12; results following heat treatment are shown in Fig. 11 and Fig. 13.

For the as-plated samples, wire pull test results of EPIG were not related to Pd deposit thickness, but improved as Au thickness increased.

For the sample following heat treatment for 16 hours at 175 degrees C, wire pull results for the EPIG film were worse, especially when Pd thickness was thinner. It was apparent that EPIG deposits with thicker Au had better WBR even with heat treatment. When both Au and Pd thicknesses were thinner, ENEPIG film had better WBR even with heat treatment, compared with EPIG film.

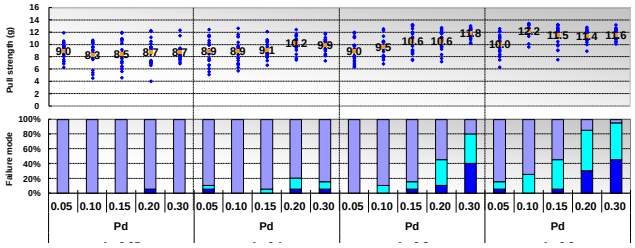


Figure 10. Wire pull test results; EPIG (Pd 0.05-0.3um, Au 0.05-0.3um) as-plated

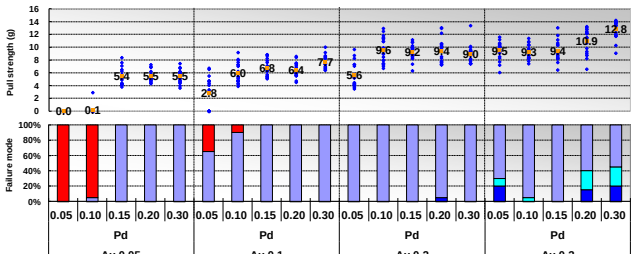


Figure 11. Wire pull test results; EPIG (Pd 0.05-0.3um, Au 0.05-0.3um) after heat treatment

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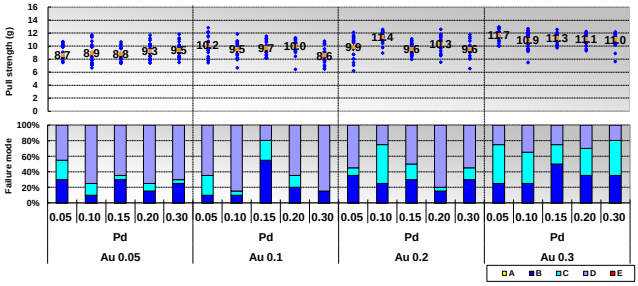

Figure 12. Wire pull test results; ENEPIG (Ni-P 6um, Pd 0.05-0.3um, Au 0.05-0.3um) as-plated

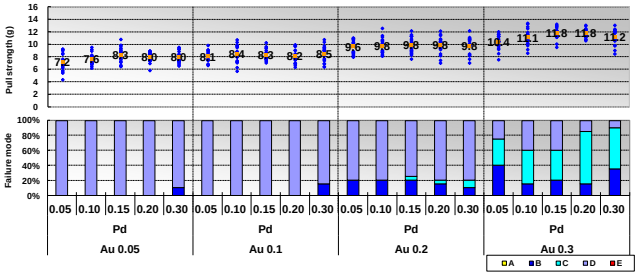

Figure 13. Wire pull test results; ENEPIG (Ni-P 6um, Pd 0.05-0.3um, 0.05-0.3um after heat treatment

For EPIG and ENEPIG deposits with Au thickness of 0.1um and with Pd thickness of 0.1um, the results of wide scan and depth profile by AES were analyzed as shown in Fig. 14 and Fig. 15.

From the result of wide scan for EPIG film after heat treatment, the peak of Cu was detected; no Cu peak was detected for the ENEPIG film. It was considered that one of the factors, which EPIG film had poorer WBR after heat treatment, was Cu diffusion to the Au surface.

Also, the Pd peak was detected for the EPIG and ENEPIG films after heat treatment. From the result of the depth profile it was observed that Pd exists fully in the Au film layer. It was considered that the solid solution layer of Au and Pd was formed and this was the second factor, when poorer WBR was caused when Au and Pd thicknesses were thinner.

To preserve the WBR of the EPIG film following heat treatment, it was suggested that preventing Cu and Pd diffusion is necessary. For the EPIG film, the effect of Pd and Au thickness was confirmed by using wide scan and depth profile of AES after heat treatment as shown in Fig.16 and 17.

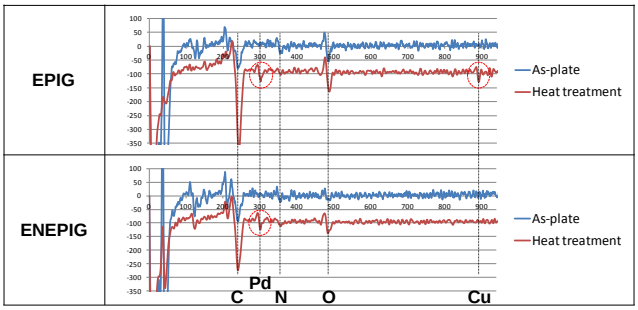

Figure 14. Wide scan results by AES; EPIG (Pd 0.1um, Au 0.1um), ENEPIG (Ni-P 6um, Pd 0.1um, Au 0.1um) as plated and with heat treatment

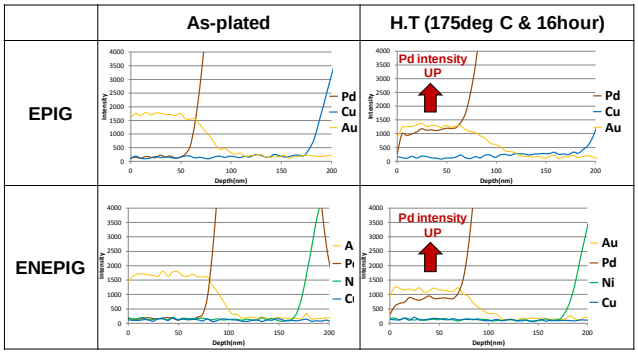

Figure 15. Depth profile results by AES; EPIG (Pd 0.1um, Au 0.1um, ENEPIG (Ni-P 6um, Pd 0.1um, Au 0.1um as plated and with heat treatment

From the result of a wide scan, the peak of Cu was detected when Pd film was thinner. However, no Cu peak was detected when Pd was thicker. Therefore, a thicker Pd film was effective in preventing Cu diffusion to the Au surface. Also, the peak of Pd with a thicker Au layer was weaker than with a thinner Au layer. From the depth profile, the ratio of Pd in the Au layer with a thicker Au layer was lower than with a thinner Au layer. The ratio of Pd and Au intensity for the depth profile was plotted for every Pd and Au thickness, as shown in Fig. 18.

The value of Au and Pd intensity used in this figure was that of 20 nm point from the Au surface. It was considered that the diffusion of Pd was independent of Pd thickness, and was greatly dependent on Au thickness. The thicker Au layer will be important for keeping a lower ratio of Pd in the Au layer. This ratio of Pd in the Au layer was related to WBR following heat treatment.

This study indicates that, when applying heat treatment for 16 hours at 175 degrees C, Pd thickness of at least 0.15um and Au thickness of 0.20um will be required.

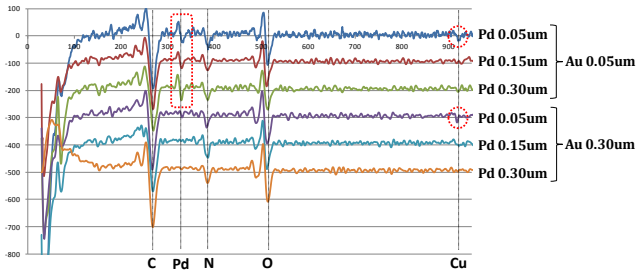

Figure 16. Wide scan results by AES; EPIG (Pd 0.05-0.30um, Au 0.05-0.30um) with heat treatment

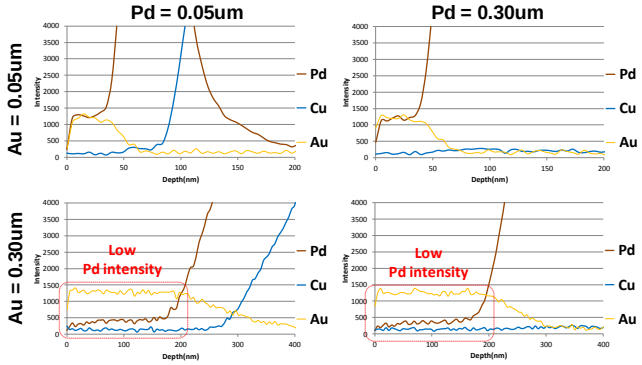

Figure 17. Depth profile results by AES; EPIG (Pd 0.05-0.30um, Au 0.05-0.30um) with heat treatment

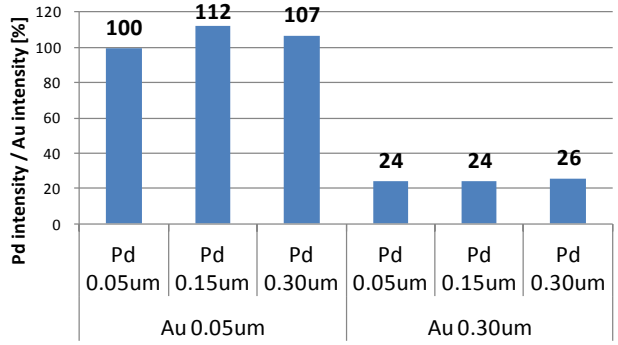

Figure 18. Ratio of Pd and Au intensity from depth profile by AES

PLASMA TREATMENT FOR WIRE BONDING

After plasma treatment, the strength of wire pull test and the broken mode improved, compared with that of the sample following heat treatment. It was confirmed by AES analysis that the peak of Cu was removed by the plasma treatment.

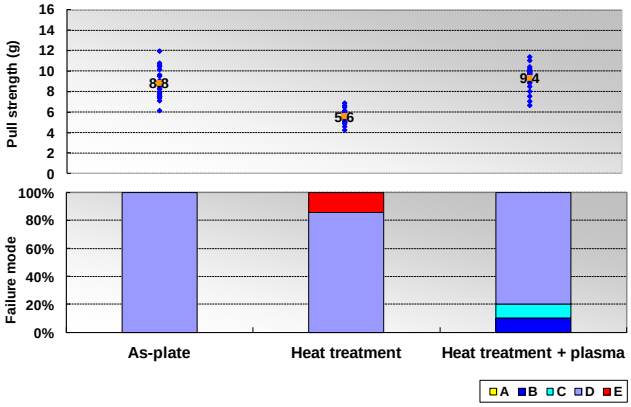

Figure 19. Wire pull test results; EPIG (Pd 0.1um, Au 0.1um as plated, with heat treatment, with heat treatment and plasma treatment

After plasma treatment, the strength of wire pull test and the broken mode improved, compared with that of the sample with heat treatment. It was confirmed by AES analysis that the peak of Cu was removed by the plasma treatment.

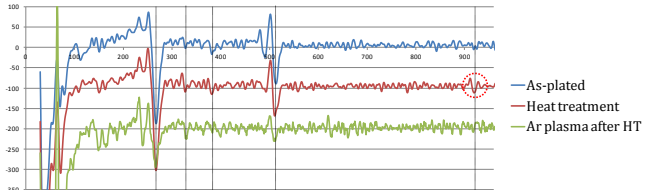

Figure 20. Wide scan results by AES; EPIG (Pd 0.1um, Au 0.1um) as plated, after heat treatment, after heat treatment and plasma treatment

CONCLUSIONS

The EPIG process had better pattern ability for narrow lines and spaces, compared with the ENEPIG process. When using LF35 as the solder ball for EPIG deposits, thin and uniform IMC layers were formed. As a result, SJR was better. When Au and Pd was thinner, EPIG film had poorer WBR after heat treatment because Cu diffused onto the Au surface and the ratio of Pd in the Au layer was higher. When suitable Pd and Au thicknesses are used for EPIG, WBR improves. It is suggested that WBR could be further enhanced by plasma treatment to the Au surface after heat exposure.

REFERENCES

1. Chi-Won Hwang, Katusaki Suganuma. J. Mater. Res., 18, 2540, Nov (2003)
2. Donald Gudeczauskas et al, 39th International Symposium on Microelectronics, October 8-12, 2006, San Diego
3. V. Vuorinen, T Laurila, H. Yu, and J. K. Kivilahti. J. appl. Phys. 99, 023530 (2006)
4. Yukinori Oda, Masayuki Kiso, Akira Okada, Kota Kitajima, Shigeo Hashimoto, George Milad, Don Gudeczauskas, 41st International Symposium on Microelectronics, Providence, RI, Nov (2008)