Iron-42 wt pct Nickel Lead Frame with Palladium-Electroplated Multi-layer for Semiconductor Packages

By J.-D. Kim, Y.-H. Baek, W.-S. Choi and K.-S. Bok

There has been considerable interest in the use of palladium for lead frame plating material for its various advantages in the semiconductor assembly process. Its usage has been confined, however, to the copper alloy lead frame as a two-layer structure: palladium over a nickel layer over copper alloy, because of severe corrosion in wet atmospheres. In this study, various layer structures with copper, nickel and palladium were electroplated on an iron-42 wt pct nickel lead frame, then packaged in the assembly line. The corrosion behavior of each layer structure was studied by using the salt atmosphere test and the electrochemical impedance method. The lead frame was plastic-molded to an SOJ-type package; the surface states after trimming and forming of the lead were investigated by optical microscope. The experimental results indicated that the additional layer formation of palladium and copper between the lead frame and the nickel intermediate layer greatly increased the corrosion resistance, and was well accounted for in terms of electrode kinetics of a metal-metal couple composite system. Additionally, it was found that the higher corrosion resistance supported good assembly properties of solderability and wire bondability.

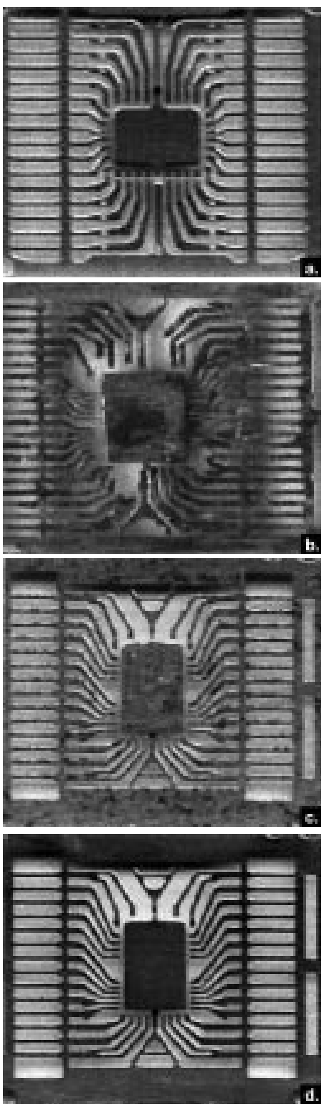

Fig. 1—Surface states for various layers of (a) Cu-LF/Ni/Pd, *(b)* alloy 42-LF/Ni/Pd, *(c)* alloy 42-LF/Cu/Ni/Pd, *(d)* alloy 42-LF/Pd/Cu/Ni/Pd*; obtained after salt spray test for 24 hr, by optical microscopy (X3).*

Special interest[1-6] has been focused on the use of palladium (Pd) instead of silver (Ag) in the electroplating of lead frames for semiconductor packages because of many advantages, such as reduction of process time resulting from elimination of tin-lead alloy (Sn-Pb) plating in semiconductor packaging and significant decrease of hazardous compounds encountered in typical semiconductor component metal finishing operations.

Actually, the Pd-electroplated copper alloy lead frame has been successfully used[1,2] as two-layer structures of nickel and Pd on the lead frame: a copper alloy lead frame under the Ni layer under the Pd outermost layer (*Cu-LF/Ni/Pd*). The Pd-electroplated iron-42 wt pct/Ni alloy (alloy 42) lead frame has not been used, however, because of its very low corrosion resistance in wet atmospheres.

Many workers,[3-6] therefore, tried to overcome the corrosion problem of the Pd electroplated alloy 42 lead frame. A three-layer structure of Cu, Ni and Pd on the alloy 42 lead frame (*alloy 42-LF/Cu/Ni/Pd*) was constructed by Akihiko and Nirino[3] in an attempt to get corrosion resistance similar to the corrosion resistance of the two-layer structure: *Cu-LF/Ni/Pd*. Lee *et al.*[4] experimentally proved, however, that the three-layer structure: *alloy 42-LF/Cu/Ni/Pd* could not endure the corrosive environment of a salt atmosphere.

Kadija et al.[5] increased the thickness of the intermediate layers of Cu and Ni on the alloy 42 lead frame from normal thickness, 1 to 4 μm each to raise the corrosion resistance. Sim *et al.*,[6] however, reported that as the thickness of the Cu and Ni intermediate layers increased over 3 μm, the wire bondability and solderability of the lead frame in the assembly process was greatly decreased. It was necessary, therefore, to develop the Pd-electroplated alloy 42 lead frame to have both high corrosion resistance and good assembly properties.

This study is concerned with the effect of an intermediate layer between the lead frame substrate and the outermost Pd

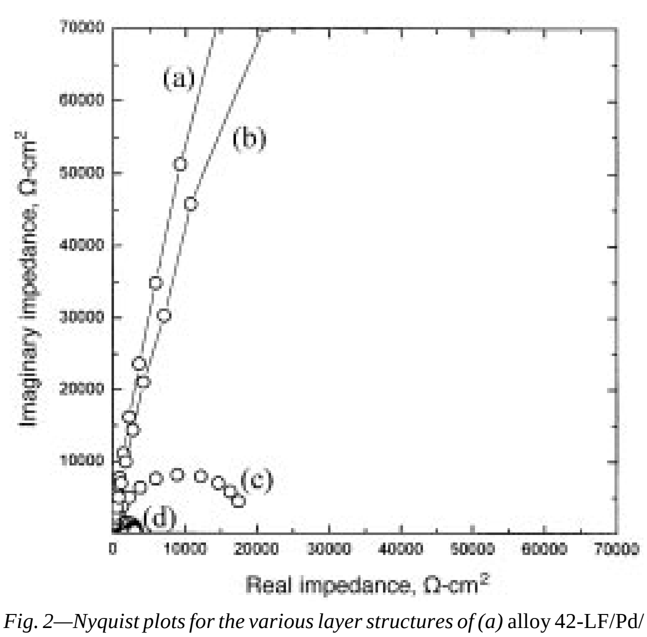

Fig. 2—Nyquist plots for the various layer structures of (a) alloy 42-LF/Pd/Cu/Ni/Pd, *(b)* Cu-LF/Ni/Pd, *(c)* alloy 42-LF/Cu/Ni/Pd, *(d)* alloy 42-LF/Ni/Pd *in 3.5 wt pct NaCl solution in the frequency range from 0.1 to 10^5 Hz at the single sinusoidal potential of 5 mV.*

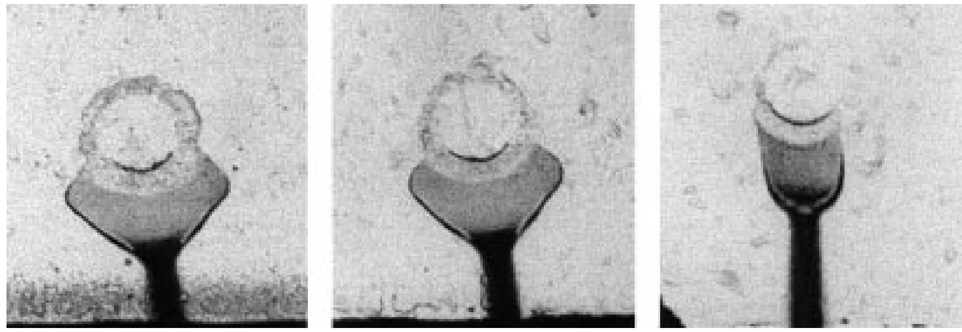

Fig. 4—Remnants of Au on the lead frame surface of the SOJ-type plastic package with the layer alloy 42-LF/Pd/Cu/Ni/Pd *obtained after Au-wire pull test by optical microscopy.*

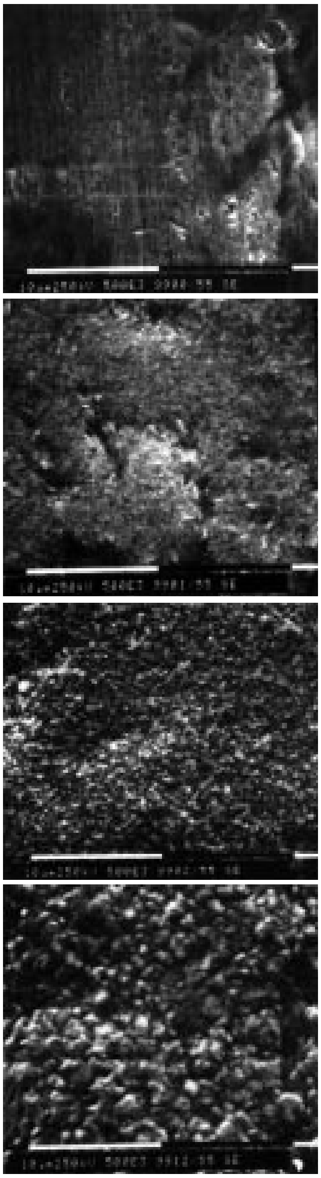

Fig. 3—Surface states of (a) alloy 42-LF/Pd, *(b)* alloy 42-LF/Pd/Cu, *(c)* alloy 42/Pd/Cu/Ni, *(d)* alloy 42/Pd/Cu/Ni/Pd, *measured by scanning electron microscopy (SEM).*

layer on the corrosion resistance of the alloy 42 lead frame and on the assembly feasibility for the plastic package. For this purpose, various layer structures consisting of Cu, Ni and Pd were electroplated on the alloy 42 lead frame.

The salt spray test and the a-c impedance measurements were carried out to measure corrosion resistance in various atmospheric and solution environments. Solderability, gold wire bondability and crack density of the lead finish were measured for determining feasibility for the semiconductor package process. From the experimental results, a highly corrosion-resistant layer structure could be obtained and it was accounted for in terms of the mixed electrode kinetics in a corrosive environment.

Experimental Procedure

In the experiments, the Cu alloy lead frame C104[7] and the Fe-42 wt pct Ni lead frame of alloy 42[7] were used. Electroplating was carried out in the cut-strip-type plating machine with a continuously circulating bath. Table 1 shows the plating conditions of each layer of the alloy. The surface morphology of the layer formation was investigated by scanning electron microscopy.

The salt spray experiment based on MIL-STD 883d 1009.8[8] was carried out to determine the atmospheric corrosion resistance of the electroplating layer. The electrochemical impedance measurements were utilized for quantitative corrosion measurement in solution environment by using Zahner No. IMD5. The electrochemical cell used in this study for impedance measurement was similar to the cells previously described in the literature.[9] The surface area of the specimen exposed to electrolyte was 1 cm^2. A platinum wire and a saturated calomel electrode (SCE) were used as counter-electrode and reference electrode, respectively. A single sinusoidal potential of 5 mV was applied over the frequency range of 10^{-1} to 10^6 Hz at room temperature in 3.5 wt pct NaCl solution.

For the feasibility test for the assembly manufacturing process, the Pd-electroplated lead frame was plastic-molded, then trim-formed to be an SOJ-type package. For surface investigation, the optical microscope and scanning electron microscope were used. The solder coverage on the lead was estimated based on the dip-and-look method.[10] Wirebond studies were performed with UTC 100 bonders in wedge/wedge ultrasonic mode, using 30-µm Au wire.

Results & Discussion

Corrosion Behavior

Figures 1a,b,c,d show the lead frame surfaces of the *Cu-LF/Ni/Pd*, the *alloy 42-LF/Ni/Pd*, the *Fe-42 wt pct Ni-LFNi/Cu/Ni/Pd* and the *alloy 42-LF/Pd/Cu/Ni/Pd* structures investigated after 24-hr salt atmosphere tests based on MIL-STD 883d 1009.8[8] by optical microscope. It was found that there was no surface corrosion apparent for the *Cu-LF/Ni/Pd* (Fig. 1a). On the other hand, severe corrosion, even resulting in broken leads, occurred for the *alloy 42-LF/Ni/Pd* (Fig. 1b).

Figure 1c indicates that some corroded areas at the lead, edge and pad regions was found for the *alloy 42-LF/Cu/Ni/Pd*. The amount of corroded area is considerably less, however, than that of the *alloy 42-LF/Ni/Pd*. It is shown in Fig. 1d that, remarkably, there is no surface corrosion for the *alloy 42-LF/Pd/Cu/Ni/Pd*, which is very similar to the surface state of the *Cu-LF/Ni/Pd*. The results indicate that the addition of Pd, even the small thickness of 0.05 µm, to the interface between the lead frame and the Cu/Ni layer plays an important role in enhancing the corrosion resistance of the multilayer plated alloy 42 lead frame.

Figures 2a, b, c and d show the electrochemical impedance plots for various layer structures obtained in 3.5 wt pct NaCl solution. It is clearly seen from Fig. 2 that the magnitude of the impedance arc corresponding to the corrosion resistance

Table 1
Layer Preparation Conditions

Process	Basic Bath Constituent	Applied Current Density A/dm^2	Temp °C	Layer Thickness µm
Pd plating*	$Pd(NH_3)_4Cl_2$	2	35	0.05
Cu plating	$Cu_2P_2O_7 \cdot 3H_2O$	2.5	55	2
Ni plating	$Ni(NH_2SO_3)_2$	4	50	2
Pd plating**	$Pd(NH_3)_4Cl_2$	2	35	0.1

* Inner Pd layer ** Outer Pd layer

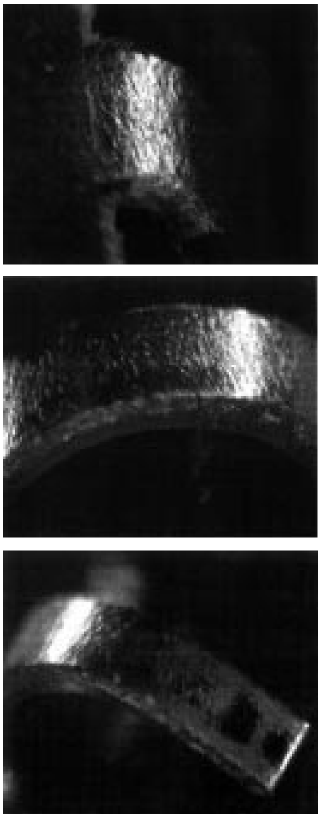

Fig. 5—The surface states of (a) shoulder, (b) bottom and (c) toe region for the SOJ-type plastic package with the layer alloy 42-LF/Pd/Cu/Ni/Pd *obtained after trimming and forming measured by 3D optical microscopy (50X).*

increases in the order: *alloy 42-LF/Ni/Pd < alloy 42-LF/Cu/Ni/Pd < alloy 42-LF/Ni/Pd = alloy 42-LF/Pd/Cu/Ni/Pd.*

The surface corrosion status (Fig. 1) change with layer structure is in good agreement with the order of the impedance arcs (Fig. 2). It means that the corrosion behavior for the multi-layer finish in the atmospheric environment is similar to that in the solution environment.

The corrosion resistance may be thought as improved by the increase in total layer thickness because of the addition of Pd from 4.1 to 4.15 µm. According to Fig. 2, however, the corrosion resistance of the *alloy 42-LF/Pd/Cu/Ni/Pd*, which corresponds to the radius of the semicircle, is more than an order of magnitude larger than that of the *alloy 42-LF/Cu/Ni/Pd*. It is thus not plausible to think that the corrosion resistance increase is brought about by the increase in total layer thickness.

In the field of corrosion kinetics,[11] it is generally agreed that even though various transient electrochemical reaction steps may be involved, the main anodic and cathodic processes during atmospheric corrosion of a metal-metal or metal-oxide composite system can be expressed as follows:

$$M = M^{z+} + ze \qquad \text{at the metal/metal interface} \qquad (1)$$

$$O_{2(g)} + 2H_2O + 4e^- = 4(OH)^- \qquad \text{at the metal/atmosphere interface} \qquad (2)$$

where M, M^{z+}, z, e, $O_{2(g)}$ and $(OH)^-$ represent the metal atom, charged metal ion, the charge number of the metal, oxygen gas and hydroxyl ion, respectively.

According to Wagner's mixed electrode theory,[12] the corrosion current density for the metal system is decreased by increasing the electrochemical potential of the anodic reaction (1) toward the more noble direction. It is thus plausible to think that the additional plating of the Pd layer between the Fe-42 wt pct Ni lead frame and the Cu layer increases the electrochemical potential of the anodic reaction (1) toward the more noble direction, resulting in the greater corrosion resistance of the layer structure alloy *42-LF/Pd/Cu/Ni/Pd* (Figs. 1 and 2).

Table 2
Pull Strength Values of Wire Bondability

Pull strength, g	Ag spot plating lead frame	Pd plating lead frame
Min.	9.5	9.0
Max.	15.5	17.0
Avg.	12.4	13.5
Standard deviation	1.73	2.19
Cp	1.62	1.44

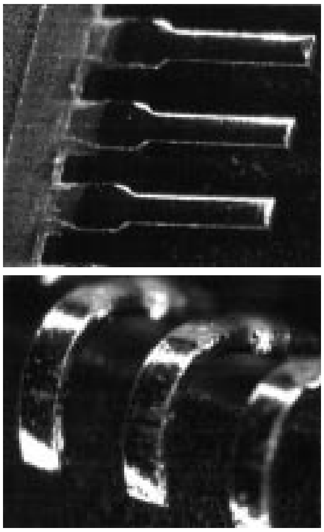

Fig. 6—Surface states of (a) trimmed, then (b) formed lead of the SOJ-type package obtained after 8 hr steam aging, then solder dipping, measured by 3D optical microscope.

Figure 3 shows surface states of (a) the *alloy 42-LF/Pd*, (b) the *alloy 42-LF/Pd/Cu*, (c) the *alloy 42/Pd/Cu/Ni*, and (d) the *alloy 42/Pd/Cu/Ni/Pd*, measured by scanning electron microscope (SEM). It was found that as the layer was electroplated, no pores or surface imperfections were formed. It is thus expected that the stable surface morphology might support good corrosion resistance. It was impossible, however, to obtain the low corrosion resistance for the structure *alloy 42-LF/Pd/Ni/Pd*, because it was attributed to the porous structure of Ni formed directly on Pd.[13]

Feasibility for Assembly

Because the high corrosion resistance to the corrosive atmospheric and solution environments could indicate feasibility for the semiconductor assembly process, some tests were conducted to insure compatibility of the *alloy 42-LF/Pd/Cu/Ni/Pd* with the requirements of the semiconductor packaging process.

Table 2 shows the wire bond reliability test results of the *alloy 42-LF/Pd/Cu/Ni/Pd* compared with the *alloy 42-LF/Ag*. Test criteria include pull strength. From the results of Table 3, it is shown that there is no statistical difference between the wirebonding properties of the *alloy 42-LF/Pd/Cu/Ni/Pd* and the silver spot lead frame *alloy 42-LF/Ag*.

Figures 4a, b and c show the remnants of Au on the lead finish surface of *alloy 42-LF/Pd/Cu/Ni/Pd* for the plastic package obtained after the Au-wire pull test. It is seen that a considerable amount of Au residue exists, indicating relatively good adherence between the Au wire and the lead frame surface.

From the wire bonding results, it can be said that the surface of the *alloy 42-LF/Pd/Cu/Ni/Pd* lead finish can withstand, without severe oxidation, the high temperature wire bonding conditions.

Figures 5a, b and c show the lead frame surfaces for the *alloy 42-LF/Pd/Cu/Ni/Pd* after lead bending of the SOJ type package measured by 3D optical microscopy. It is easily seen that there are no severe cracks formed during the trimming and forming process for the lead frame areas of (a) shoulder, (b) bottom and (c) toe.

Figures 6a and b show the lead frame surfaces, (a) trimmed, then (b) formed for the SOJ type package, obtained after 8 hr steam aging, then solder dipped and measured by 3D optical microscope. It was found that the lead frame surface has solder coverage above 95 percent. According to previous work on the *Cu-LF/Ni/Pd* alloy for semiconductor packages, the solderability can be decreased mainly because of oxidation of Cu atoms on the lead finish.

Abys *et al*.[14] reported that Cu migration onto the outer Pd surface occurs through the easy paths in the intermediate Ni layer, such as cracks or pores during the assembly process for the *Cu-LF/Ni/Pd* layer, and this kind of surface contamination can be detrimental to solderability and wire bonding properties. It can thus be understood that good solderability results (Figs. 6a,b) are in good agreement with the lower crack results (Figs. 5a,b,c).

Conclusions

From the experimental results in this study, the following conclusions can be reached.

1. Corrosion resistance measurements in a corrosive atmospheric environment (salt spray test) and in solution environment (a-c impedance technique) show that high corrosion resistance of the Pd-electroplated alloy 42 lead frame can be obtained by formation of the multi-layer structure, *alloy 42-LF/Pd/Cu/Ni/Pd*.
2. The increase in corrosion resistance resulting from the additional plating of Pd between the lead frame and the Cu/Ni intermediate layer accounts well for the change in the anodic reaction during the corrosion process toward the more noble direction owing to the Pd plating on the lead frame.
3. It is found from the results of solderability and wire bondability tests that the high chemical stability and relatively lower crack formation of the *alloy 42-LF/Pd/Cu/Ni/Pd* makes feasible the layer structure for the assembly manufacturing process.

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