Thick Palladium Coated Copper (PCC) Wire BSOB Bonding on a Pre-plated Frame Chip on Lead Package

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Abstract
Palladium coated copper wire has been introduced in the semiconductor wirebond industry to addressed issues related to bare copper wire, mainly fast oxidation. The presence of the palladium coat provides protection to oxidation of bare copper wire core for a short period of time. This is very useful especially on bond stitch on ball (BSOB) wirebonding where a stitch bond is placed on top of bump ball. The relative hardness of the coated copper wire however possess significant challenge for large scale BSOB wirebonding. Conventional gold (4N Au) wirebonding is the best choice but with rising cost the alternative version is preferred by the industry. Silver (88, 92, 95% Ag) alloy wires offers cheaper cost solution but still remain to be proven for high reliability wirebonding. Alloying also of Ag wires results to an increase in the resistivity of the wire. This is unwanted especially on Mosfet devices where RDSon resistance is significantly controlled. Combining cost and reliability performance requirements, palladium coated copper wire is the still best choice.

1. Introduction
BSOB wirebonding of palladium coated copper (PCC) especially with 50um thick wires (with 2% to 3% Pd content) requires high bonding parameters to initiate intermetallic formation between two dissimilar metals because of its hardness and the higher melting point of palladium. As a result, significant splash out (greater than 5um) can be seen on bonding pads (for Al, AlCu, AlSi, AlSiCu pads) and ball neck stress for ball on lead bonding can be observed. Chip on lead (COL) package is a unique packaging where there is a significant reduction of leadframe material as a die is directly place on top of the leads, but the reduction of leadframe flag to support the die induces instability on the package as there is less support for both materials. The conventional leadframe material is normally made of copper base frame and leads are plated with silver. Pre plated leadframes with the same performance as copper base frames are alternative type of leadframes to eliminate leadfinger plating process. This type of frame normally uses Nickel, Palladium and gold flash, together with Copper as base material. This is harder than the usual leadframes and as such more difficult to bond with PCC wire. Thick wire BSOB bonding on a COL QFN device possess both challenges mentioned above. Table 1 shows property of different wire base material types and table 2 for Alloys.

<table>
<thead>
<tr>
<th>Material Property</th>
<th>Units</th>
<th>Au</th>
<th>Cu</th>
<th>Ag</th>
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<tbody>
<tr>
<td>Thermal Conductivity</td>
<td>W/mk</td>
<td>320</td>
<td>400</td>
<td>430</td>
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<tr>
<td>Electrical Resistivity</td>
<td>mohm</td>
<td>2.2</td>
<td>1.72</td>
<td>1.63</td>
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<td>Young’s Modulus</td>
<td>Gpa</td>
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<td>130</td>
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<td>Poisson Ratio</td>
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<td>0.34</td>
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<td>Yield Stress</td>
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<tr>
<td>Vickers Hardness</td>
<td>Mpa</td>
<td>216</td>
<td>369</td>
<td>251</td>
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</table>

Table 1. Pure Wire Characteristics

<table>
<thead>
<tr>
<th>Material Property</th>
<th>Unit of Measure</th>
<th>PCC</th>
<th>Au</th>
<th>Ag Alloy</th>
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</thead>
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<tr>
<td>Vickers Hardness</td>
<td>HV</td>
<td>70-80</td>
<td>44.49</td>
<td>50-60</td>
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<tr>
<td>Hardness</td>
<td>um</td>
<td>80-100</td>
<td>69.8</td>
<td>69.80</td>
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<td>Density</td>
<td>g/cm³</td>
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<td>15.2</td>
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<td>Elastic Modulus</td>
<td>Gpa</td>
<td>90-100</td>
<td>80.90</td>
<td>60.70</td>
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<td>Recrystallization temp</td>
<td>degC</td>
<td>500-550</td>
<td>500-550</td>
<td>500-550</td>
</tr>
<tr>
<td>Melting point</td>
<td>degC</td>
<td>1000-1000</td>
<td>1000-1000</td>
<td>980-1020</td>
</tr>
<tr>
<td>Fusing current</td>
<td>A,length=10mm</td>
<td>0.58</td>
<td>0.47</td>
<td>0.44</td>
</tr>
<tr>
<td>Resistivity</td>
<td>ohm/mm at 25°C</td>
<td>1.9</td>
<td>2.9</td>
<td>3.3</td>
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<tr>
<td>Thermal conductivity</td>
<td>W/mk</td>
<td>401</td>
<td>317</td>
<td>429</td>
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<tr>
<td>Coefficient of thermal expansion</td>
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<td>17</td>
<td>14</td>
<td>19</td>
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<tr>
<td>Elongation</td>
<td>%</td>
<td>5-17</td>
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<td>Purity</td>
<td>%</td>
<td>99.98</td>
<td>95</td>
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Table 2. Doped Wire Characteristics
2. Evaluation and Characterization

Two types of pre-plated lead frames were used for new product qualification for ESD protection devices. First the normal pre-plated leadframe with NiPdAu and Cu base material has the following dimensions and plating composition consisting of; 
Ni: 0.254~1.27um; Pd: 0.00508~0.0254um; AuAg: 0.01016~0.0635um

Second type of material used is known as roughen pre-plated material with Ni: 0.5-2um; Pd 0.01-0.15um; Au 0.003-0.015um. For both types of leadframe, Bruker tester was used to measure leadframe roughness.

Main difference between these two types of leadframe is the surface roughness, normal PPF have smooth and shiny surface while a roughen PPF has corrugated surface. The difference in appearance is due to the surface morphology.

Normal PPF reflects light while Roughen PPF distribute the light, hence resulting to darker manifestation. Surface roughness testing showed the former had an Ra=0.137um while the latter had an Ra=0.69um

2.1 Free Air ball study
The 50um PC free air ball (FAB) study was conducted with the use of ASM Cu Kit as shown in figure 3. The Cu kit gas is consist of 5%Forming gas (H2N2) and 95% Nitrogen gas (N2). A DOE was conducted to determine FAB characteristics of the 50um PCC wire. The DOE is focus on understanding the interaction/behavior of EFO current and EFO time.

Interaction plot summary showed that both time and current is significant to the increase in FAB size. Target is set at 165 (Amp) current and 1.58(ms) EFO time. An average FAB size of 105um
is obtained and is used throughout the evaluation process.

Figure 4: Variability Chart FAB

Electron probe micro analysis (EPMA) analyzer showed the distribution of both copper and palladium on the FAB. Blue color indicates that the Palladium is mixed on the copper free air ball. As per previous technical studies [5], this type of Free air ball utilizes a high current, low EFO time parameter combination.

Figure 5: EPMA of FAB

2. 2 Normal PPF Leadframe

A wDFN3030 package was utilize to evaluate the performance of 50um PCC wire on chip on lead package. Die has a 4mils thickness and is using nonconductive wafer back coat and is then die bonded on normal PPF leadframe. Die is sitting on leads and center ground lead. Characterization of the bondability performance was necessary to have a consistent response. Critical responses include ball shear, wire pull, ball dimension must be optimize. BSOB wirebond on a 4um AlCu top metal is successful with settings characterize as shown from previous evaluations [5].

Figure 6: 50um PCC BSOB wirebond on COL package

For this configuration, challenge was mostly on bonding the thick/hard 50um PCC wire on unstable chip on lead PPF package. Large scale bonding initially encountered severe occurrences of non-stick on the lead area. Base from defect manifestation, due to high settings used (High base power/low force combination) the plated area seems to be peeling off from the Cu base frame. Whereas using a lower power/high force combination, the ball on lead NSOL is much worse. EDX analysis of the affected sample did not show significant element to cause NSOL.

Figure 7: Ball on lead, Bump on die and Cross section of BSOB on die
To enhance bondability of 50um PCC wire on this PPF leadframe several evaluations were done including (1) improvement of the leadframe design to eliminate micro-bouncing effect for overhang leads and (2) DOE characterization on first bond ball on lead settings were conducted. So as not to increase the base power to a very high settings, just to make it adhere on the leadframe, auxiliary settings such as scrub power and scrub force was included on the DOE matrix. Finalized settings and large scale validation have shown passing bondability requirements with improve Non stick on lead (NSOL) issues when bond scrub power/force combination is added. The settings have been fan-out to other normal PPF lead frames with the same composition/cross section layout and prove to be feasible in high volume manufacturing with BSOB wirebonding (~10M units/week loading).

2.3 Roughen PPF leadframe

For the roughen leadframe, ball on lead bonding is more stable. The same plating scheme was used as compared with the normal plated PPF leadframe but with slightly thicker Pd layer. Another major difference is that roughen PPF has Ra=0.69um which helps hold the ball in lead while using a high power/low force combination. Cross section of the ball on lead shows that the edges of the ball bond have variability on adhesion but the majority of the ball area have “grip” effect on the leadframe.

This type of leadframe have been qualified also with passing reliability data. However during large scale production validation, several intermittent
NSOL was also encountered. EDX analysis did not show significant element to cause NSOL issue.

Figure 11: EDX test Analysis for NSOL

Further investigation on the leadframe included SEM inspection of the affected samples and it was found out that it has different SEM surface morphology. In addition the roughness test measurement utilizing Bruker test have shown significant reduction on surface roughness for affected leadframes. Affected leadframes have $Ra=0.23\mu m$. After replacing the leadframe batch with $Ra>0.4\mu m$, NSOL was contained.

Figure 12: Unaffected and affected leadframe surface morphology
Unaffected:

$$Ra=0.409\mu m$$

Affected:

$$Ra=0.233\mu m$$

3.0 Reliability Performance

For the two configurations of pre plated leadframes reliability test includes AC96hrs, UHAST192hrs, HAST192Hrs, HTRB1008hrs and TC2000cycles. All requirements were met with zero failures.

4. Conclusions

The study have shown optimum settings for Free Air ball to maintain good adhesion of thick PCC BSOB ball on die and lead surface. The FAB tend to increase in size with higher bond current and time. For this device qualification, high EFO
current/ low time combination was utilized to maintain consistent Pd distribution as seen on EPMA analysis.

The ball bonding on Pre-plated leadframes have different challenges but can be addressed by optimizing current base parameters and maintaining desired requirements. For the normal PPF leadframe, the bond parameter requirement is high power/low force in combination with optimize scrub power/force settings is required. Also mechanical rigidity of leadframe leadfingers especially for chip on lead products is desired. For the roughen leadframes, enhanced Pd layer of the leadframe can help stabilize the bondability but its roughness consistency will need to be maintain as well to prevent production issues.

Overall the two pre-plated leadframe configurations passed MSL1 level requirements and is already in high volume manufacturing.

5. Acknowledgments

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6. References

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