Influence of Textured Nickel/Palladium/Gold-Silver (Ni/Pd/Au-Ag) Layer on Pre-plated Leadframe for Automotive Applications

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Abstract. High quality and reliability of integrated circuit packaging is required for automotive applications due to the safety concerns. Therefore, elimination and controlling the package defects which can lead to reliability failure is essential. One of the defects that leads to reliability issue is delamination. This study presents the influence of textured leadframe surfaces on the surface wettability and delamination occurrence in automotive package unit. Standard bare Cu leadframe was used as comparison. The leadframe surface was textured with Ni/Pd/Au-Ag using electroplating technique. The surface morphologies of both bare and textured leadframe were characterized using field-emission scanning electron microscope and optical profiler. The energy dispersive spectroscopy was used to quantify the elemental composition of the samples. All samples went through the wettability test under two conditions, which were room temperature and 175°C. The reliability test of complete package was subjected to moisture sensitivity preconditioning level 1 according to IPC/JEDEC STD 020 and the baking process was performed at 125°C for 24hrs followed by soaking process under the condition of 85°C and 85% relative humidity. Scanning acoustic tomography according to IPC/JEDEC STD 035 was performed after three cycles of infrared reflow at 260°C. Higher surface roughness was observed for pre-plated leadframe (PPF) compared with bare leadframe. The lowest value of average contact angle (~55°) was observed for PPF at 175°C indicated better wettability feature. Furthermore, no delamination occurrence was observed for PPF sample compared with bare copper leadframe. The obtained result reveals that leadframe with textured surface of Ni/Pd/Au-Ag improved interfacial surface adhesion which eliminated the delamination defect and thus improved the package robustness and reliability.

Keywords: Ni/Pd/Au-Ag, Texturing, Wettability, Delamination, Automotive
1. Introduction

A reliable and full capability of integrated circuit (IC) device is obligatory in automotive applications. This device requires high quality and robust packaging solution as any functionality impairment will lead to reliability and safety concerns at field application. The device used in automotive system application such as air bag, door lock and tire pressure strongly requires high performance and without failures. Therefore, improvement in package reliability that satisfied the current automotive standard is vital. One of the common failures in IC packaging is delamination that affects the product quality. Delamination is defined as weak interfacial adhesion (loss of adhesion) of a film from a substrate. This failure caused by coefficient of thermal expansion (CTE) mismatch between different types of dissimilar material interfaces at elevated temperature. In IC packaging, delamination occurrence is commonly observed between mold compound and metal substrate interfacial [1-3].

Metal substrate or copper-based (Cu-based) leadframe is widely used in IC packaging for chips mounting and electrical connection between IC chips and external leads of the package [4-5]. This day, pre-plated leadframe has gain popularity and extensively used due to its advantages, ability to improve the leadframe solderability and also improve the die attach, wire bonding and mold compound adhesion to the base substrate [6]. This PPF is also a reliable alternative to the typical Ag-plated Cu leadframe that suffered with tin (Sn)-whisker issue and toxic lead-based plating. Thus, NiPd-based pre-plated leadframes, NiPdAu, NiPdAu-Ag and NiPdAu-Pd have been introduced in order to remove certain hazardous materials in the process and at the same time meets the environmental regulations. In addition, the application of multi-layer plating on the Cu leadframe helps to eliminate the post-plating process of the final package’s leads [7-9]. The multi-layer plating plays different role to the Cu leadframe. The Ni layer which is plated on the Cu surface provides corrosion and oxidation resistance to the leadframe. This layer also prevents Cu (from the leadframe) diffusion into the Pd layer. The Pd layer which plated on the Ni layer hinders the underlying Ni surface from being oxidized and prevents diffusion from the top layer to the Ni layer. The top layer, Au or Au alloy prevents the Pd layer from being oxidized and facilitates the wire bonding and soldering process. This layer also helps to prevent outgas absorbed by Pd layer. In addition, surface hardness can be reduced by adding with Ag for better bondability [4,10].

Excellent interfacial adhesion between mold compound and Cu leadframe is in demand in order to overcome the delamination issue. One of the techniques that can be used to improve the interfacial adhesion is modification of the plated surface. The modification or roughening process can be performed on the top of copper lead frame surfaces followed by Ni layer prior to Pd plating process. This modification improves the surface energy and high mechanical interlocking between Cu leadframe surface and mold compound can be achieved. A rough surface that produced by this modification is not only helps to improve adhesion but also effective with downbonds [6-7,11]. However, optimum surface roughness is essential to ensure interfacial adhesion. This is because a very rough surface is unfavourable from the adhesion standpoint while a smooth substrate tends to reduce the adhesion degree [2].

This research studied the influence of textured (roughened) PPF surface which comprises of Ni/Pd/Au-Ag layer on the wettability property and surface delamination for automotive device applications.

2. Material and Method

2.1. Substrate Preparation

A commercial Cu alloy leadframe (C194) was used as a substrate in this study. These materials were obtained from one of the leadframe supplier. The dimension of the substrate used was 219.6mm x 31.5mm x 0.127mm (Length x Width x Thickness). Prior to electroplating process for the PPF preparation, the Cu substrate was cleaned using anodic cleaning process in a detergent solution at certain current density for a certain time. The substrate was then rinsed with de-ionized (DI) water. The substrate went through an acid cleaning process and finally rinsed with DI water. The cleaned Cu substrate
underwent roughening treatment based on the electroplating technique. The Cu substrate was submerged into Ni solution in order to form an intermediate layer. This process was associated with an application of modulated current to the plating solution and metal substrate. The final thickness of plated Ni was ~0.5μm. The second layer of Pd was electroplated on the underlying Ni layer with the thickness of ~12nm. The top layer which was Au alloy (Au-Ag) layer was then electroplated on the Pd layer with the thickness of ~5nm. The schematic diagram of the prepared PPF is depicted in figure 1. In addition, bare Cu leadframe from the same supplier was used as comparison.

2.2. Surface Characterization
The surface morphology of the sample was characterized using digital microscope (Keyence VHX-6000) and field-emission scanning electron microscope, FESEM (Zeiss Merlin). In addition, the elemental compositions of the sample were measured using energy dispersive spectroscopy, EDS (Bruker Quantax System) and the sample surface roughness was characterized using optical profiler (Bruker ContourGT).

2.3. Wettability Test
The surface wettability of metal substrate surface was measured by self-fabricated contact angle equipment. Two samples were prepared for this test. One of the samples was exposed to air at room temperature while another sample was exposed to 175°C for 120s in order to simulate the manufacturing molding process. DI water was then dropped onto both samples surface for wettability test.

2.4. Reliability Test
Prior to reliability test, the PPF and bare Cu leadframe underwent all the manufacturing assembly processes to become a complete IC package. This finish part was subjected to moisture sensitivity preconditioning level 1 (PC-MSL 1) which the baking process took 24hrs at 125°C. A soaking process took place in moisture and temperature chamber under the condition of 85°C/85RH (relative humidity). The sample then went through an infrared reflow at 260°C for three cycles. This reliability test was followed the IPC/JEDEC STD 020 (Moisture/Reflow Sensitivity Classification for Non-Hermetic Solid State Surface Mount Devices) standard. Any delamination failure of the sample could be detected after this process. In addition, scanning acoustic tomography, SAT (Sonix Echo) was used to measure the delamination of the sample. The SAT frequency was set to 75MHz C-SCAN, 23.3uS water path and 55dB of attenuation. This SAT testing was followed IPC/JEDEC STD 035 (Acoustic Microscopy for Non-Hermetic Encapsulated Electronic Components) standard.
3. Results and Discussion

3.1. Surface Morphology

Microscope and FESEM images of the leadframe surface for bare Cu and PPF are presented in figure 2 and figure 3, respectively. The difference of the surface morphology for bare Cu leadframe and PPF can be clearly seen from both Microscope and FESEM images. Figure 3(a) depicts that the surface morphology of bare Cu leadframe is relatively smooth compared with PPF surface (figure 3(b)). A uniform grain size and shape can be observed on the roughened PPF surface (figure 3(b-ii)). Similar observation of PPF surface structure has been published and reported, previously [7]. In addition, the average surface roughness for bare Cu surface and PPF was about 150nm and 275nm, respectively. This result shows that the PPF surface is more roughen than bare Cu surface. Furthermore, the range of grain size thickness for PPF was between 0.8μm and 1.5μm. Basically, rough metal surface increases the leadframe surface area and provides mechanical interlocking between leadframe surface and mold compound. Therefore, the interfacial adhesion of dissimilar surface materials can be improved. This improvement helps to control the delamination occurrence and at the same time improve the package reliability. Furthermore, the rough surface keeps the stress on the ball and stitch bonds low. This function hinders broken stitch bonds and lifted ball. On top of that, rough leadframe surface also preserves the thermal path [6-7,12].

Elemental compositions for both bare Cu leadframe and PPF leadframe are exhibited in figure 4, respectively. No foreign elemental has been observed for bare Cu leadframe (figure 4(a)). As expected, the main four electroplating elements can be clearly seen for PPF leadframe surface, which were Ni, Pd, Au and Ag (figure 4(b)).

(a)                                                              (b)

Figure 2. Microscope images of the surface (a) bare Cu leadframe sample, (b) PPF leadframe sample.
Figure 3. FESEM images of the surface (a) bare Cu leadframe with different magnifications, (b) PPF leadframe with different magnifications.

Figure 4. Elemental compositions (a) bare Cu leadframe, (b) PPF leadframe.
3.2. Wettability Test
A comparison of wettability result for both bare Cu and PPF leadframe is presented in table 1. Lower average contact angle was observed for bare Cu leadframe (~58°) compared with PPF (~71°) when both samples were exposed to air at room temperature. However, the lowest average contact angle was obtained for PPF (~55°) after exposure to 175°C for 120s. This result shows that PPF possesses better wettability feature at molding compound temperature compared with bare Cu leadframe. In addition, good wettability and clean surface is demonstrated by a small contact angle value [13].

Table 1. Comparison of contact angle result for both bare Cu leadframe and PPF leadframe.

| Conditions     | Bare Cu Leadframe | PPF Leadframe |
|----------------|-------------------|---------------|
|                | Average Contact   | Average Contact |
|                | Angle (°)         | Angle (°)     |
| Room Temp.     | 58.02             | 71.23         |
| 175°C          | 66.28             | 55.16         |

3.3. Reliability Test
The delamination defect of package unit can be observed after SAT was performed. Figure 5 shows the SAT images for both bare Cu leadframe and PPF leadframe. The delamination defect is indicated by the red. Therefore, each package unit from bare Cu leadframe sample was suffered from delamination. However, no delamination was observed for all packages from PPF leadframe sample. This result shows significant improvement in adhesion between mold compound and roughened leadframe surface with no delamination occurrence was observed. This observation was also reported by previous reports [1,6]. Hence, roughened the leadframe surface helps to improve interfacial adhesion strength and possible to reduce and eliminate the delamination problem between mold compound and leadframe surface.
4. Conclusion
Dissimilar material interfaces caused by CTE mismatch leads to the lack of interfacial adhesion between mold compound and leadframe surface. This problem becomes more serious with delamination occurrence in the automotive package device which any functionality impairment will lead to safety and reliability concerns at field applications. However, the severe defect such as delamination can be reduced and eliminated with several improvements. One of the improvements that can be performed is by leadframe surface modification. This modification will create a rough leadframe surface and therefore increase the leadframe surface area. Thus improves the mechanical interlocking between leadframe surface and mold compound. An improvement in the interlocking of both surfaces leads to improve the interfacial adhesion bonding joint strength and at the same time helps to control the delamination defect of the package. Sample with roughen surface (PPF) shows better wettability feature at high temperature with the lowest average contact angle value compared with bare Cu leadframe. In addition, no delamination occurrence was observed for PPF sample compared with bare Cu leadframe sample. As conclusion, textured and roughened leadframe surface will influence the wettability feature and delamination occurrence and subsequently affect the device reliability for automotive package applications.

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