

Copper Migration Induces Discoloration on a NiPdAu Surface

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Abstract— Pre-plated NiPdAu surface finish is one of the most common terminal finishing in the semiconductor and electronics industries. The plated surface, usually on top of a copper base material, prevents corrosion and promotes solderability for component attach. Herein, we report the analysis of a discolored NiPdAu surface via scanning electron microscopy – energy dispersive spectroscopy (SEM-EDS), time-of-flight secondary ion mass spectrometry (TOF-SIMS) and X-ray photoelectron spectroscopy (XPS). The surface determinants found in these series of surface analyses indicate the presence of copper, migrating from the unplated pillars of the leads.

Keywords— Discoloration, NiPdAu, migration, surface, corrosion.

I. INTRODUCTION

Leadframe-based packages are often made from Cu alloy base material. Corrosion-resistant metals like Au, Ag, Sn or their alloys, plate portions of the strip, like leads and pads. One of the most common surface finish is the NiPdAu, designed to provide mechanical and chemical protection against corrosion and physical abrasion, rendering the surface solderable even after the assembly and use. In the NiPdAu finish, the Ni layer is designed as Cu diffusion barrier, due to the small diffusivity of Cu into Ni [1-8], to prevent the diffusion of Cu towards the surface and its subsequent oxidation. Moreover, the thin Pd layer is necessary to prevent the oxidation of Ni [9], which would render the surface non-solderable. Finally, a flash of Au is introduced to prevent oxidation of Pd. This plating layer construction has been proven effective as long as porosity between layers, plating imperfections, scratches, pits and other defects are not present.

The presence of copper on the plated surface via diffusion through the plating layers, or migration from the unplated surfaces can pose aesthetic and functional failures in semiconductor and electronic packages. Herein, we report the analysis of a discolored NiPdAu surface via scanning electron microscopy - energy dispersive spectroscopy (SEM-EDS), time-of-flight secondary ion mass spectrometry (TOF-SIMS) and X-ray photoelectron spectroscopy (XPS). The surface determinants found in these series of surface analyses indicate the presence of copper, migrating from the unplated pillars of the leads.

II. EXPERIMENTAL DETAILS

NiPdAu surfaces on Cu base material with and without discoloration were subjected to a battery of surface analytical tools. SEM micrographs and elemental analysis were done using a Philips XL30 SEM and an integrated Oxford EDS

system. TOF-SIMS analysis was performed using IONTOF TOF.SIMS⁵ in the positive and negative polarities using Bi⁺ primary beam. XPS analysis was done using PHI5000 Versaprobe III with Al mono source 50 μ m, 12.5W, PE of 280 eV, a takeoff angle of 45°, and a dual beam neutralizer configuration. Surface cleaning was done for 10 min under Ar⁺ etching at 0.5 kV followed by a 10 min of Compucentric Zalar rotation sputtering.

III. RESULTS AND DISCUSSION

NiPdAu surface on Cu with and without discoloration is shown in Fig. 1. The highlighted leads are adjacent to one another, where one exhibits pronounced discoloration. High magnification optical image shows a darker uneven color on the surface. This discoloration is discernible in automatic optical inspection systems used to screen out rejects in the assembly line. The occurrence of the discoloration was evaluated as a cosmetic defect, which are defects that affect the appearance of the package without affecting the function of the device. In this case, the affected unit remains solderable per JEDEC standard (JESD22-B102E) following time zero, thermal aging at 150 °C for 8 and 16 h, and steam aging for 1 and 8 h.

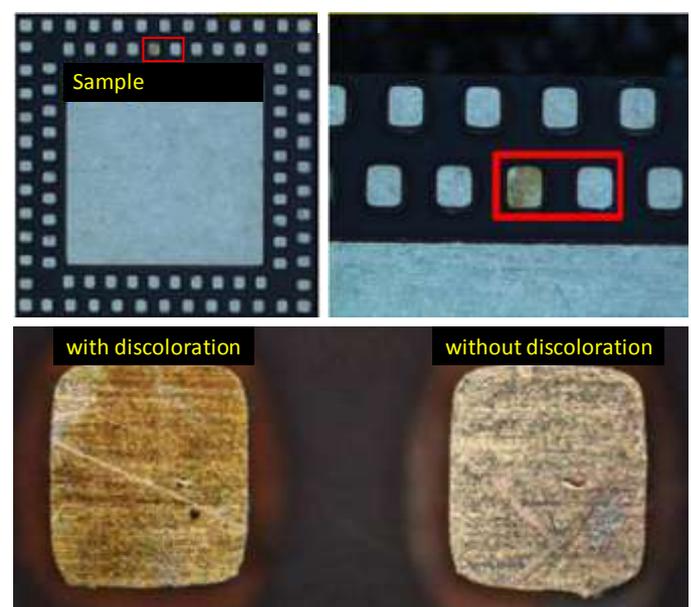


Fig. 1. NiPdAu on Cu surface with and without discoloration.

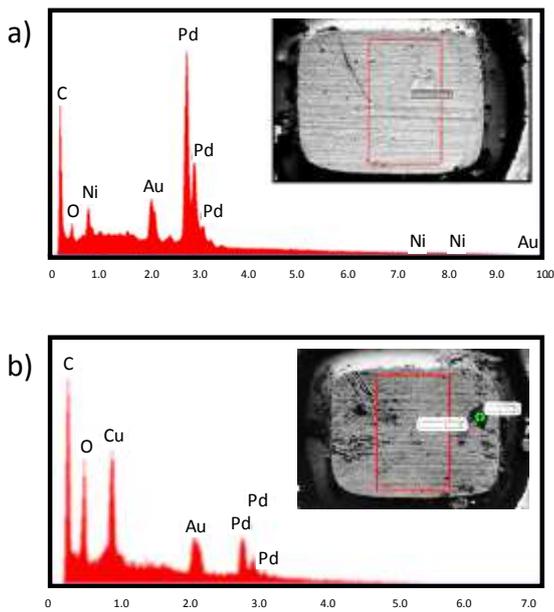


Fig. 2. SEM micrographs and EDS spectra of NiPdAu a) without and b) with discoloration.

To have a better look at the surface of these leads, SEM micrographs were taken and EDS area scan were performed (Fig. 2). The surface without discoloration has minimal surface contamination, and the striations inherent in the manufacturing process are visible. In contrast, the surface exhibiting discoloration is visibly contaminated with foreign materials, mostly located on the edges of the leads. Elemental analysis reveal that the surface without discoloration indicate the expected surface components, which are Ni, Pd and Au, with minimal traces of C and O, which are organic adherents

from the environment. However, the discolored surface exhibit Cu, Pd and Au, suggesting that the surface is contaminated by Cu. The Ni subsurface falls beyond the penetration depth of the analysis, resulting in the very weak signal. Moreover, pronounced increase of the C and O was indicated by the spectrum. The O is significantly increased, suggesting that the copper on the surface formed an oxide.

Since the penetration depth of EDS is up to 1 μm , a more surface sensitive analytical tool was explored. Fig 3 shows the TOF-SIMS spectra of the surface with and without discoloration. The penetration depth of this method is 5 - 10 nm, ensuring the surface determinants and their relative concentration could be extracted. The high O in the discolored lead confirms surface oxidation. The presence of Na^+ , K^+ , Ca^+ and Cl^- suggest contamination from handling. The observed oxidation is accelerated by these ionic contaminants [10-11]. Cu is found on the surface at higher concentration in the discolored lead confirming the possibility of Cu migration. Oxidized Cu has different colors depending on the thickness of the oxidized layer (Fig. 4).

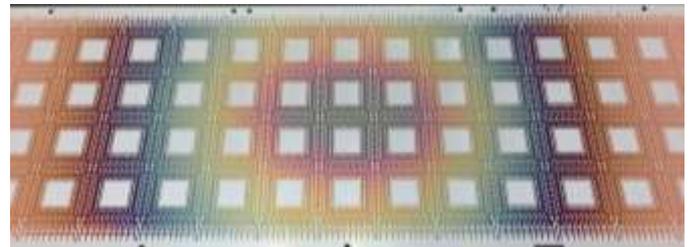


Fig. 4. Cu frame heated at 150 $^{\circ}\text{C}$ for 15 min to induce differential oxidation.

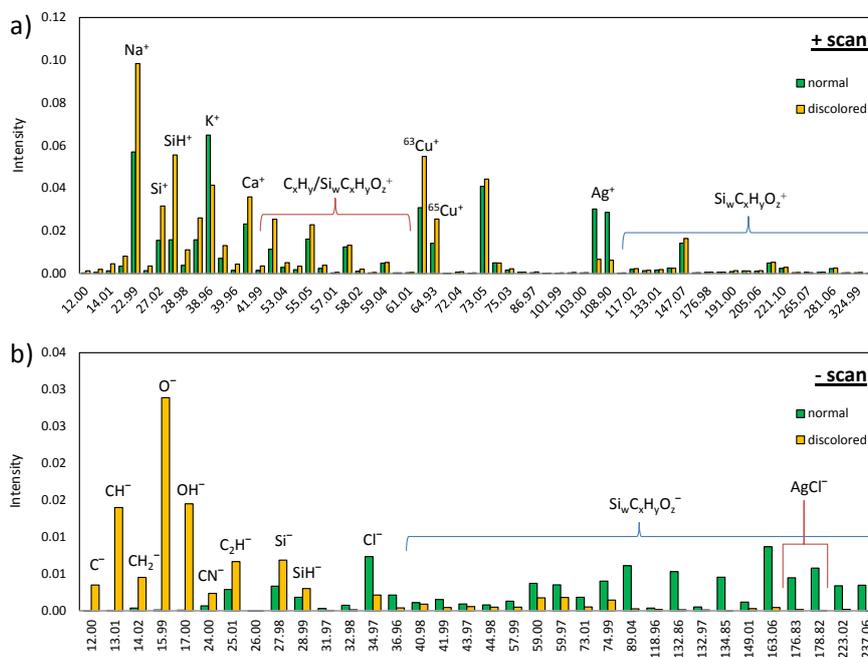


Fig. 3. TOF-SIMS a) positive and b) negative scan of normal (green) and discolored (yellow) surface.

We surmise that the Cu comes from the crown migrating to the surface. The creeping is possibly accelerated by the ionic contaminants detected at the surface. These TOF-SIMS results correlate with SEM-EDS results. In addition, the concentration of $Ag^+/AgCl^-$ is higher in the normal leads compared with the discolored lead. This is not related to discoloration since by design, the other side of these leads are plated with Ag. The occurrence of Ag is also not a functional concern because there is low risk in solderability, *i.e.* Ag is solderable. Other surface components such as SiH^+ and $Si_wC_xH_yO_z^-$ are common surface residues from tapes/liners used during the assembly of these devices. The concentration of these polysilicone adhesives are low and does not pose a risk, as supported by the passing solderability tests done on these units.

Another test was done to ascertain the surface composition of these samples. XPS analysis can analyze up to 1 nm from the surface making it one of the most surface sensitive analytical technique [12]. Fig. 5 shows the XPS spectrum of surfaces with and without discoloration in the as-received and after sputter cleaning configurations. Etching was done to remove the thick surface contamination and to ensure that the actual surface next to the topmost Au layer is detected and analyzed. Both good and dark pads appear heavily covered by organic contamination at the surface, containing C, O, Na and Si, which are coming from handling and the polysilicone tape used during assembly. After sputter cleaning, organic contamination is still present but the Cu signal is clearly visible in all measured pads. The Cu and O concentration in the discolored pad is higher, consistent with the EDS and TOF-SIMS results, indicating that the oxidized Cu on the surface of the NiPdAu surface causes the discoloration.

Based on the results, the mechanism of Cu migration and subsequent oxidation is proposed. The Cu originates from the exposed copper crown. Migration on the surface could be influenced by environmental conditions like the handling (manual or automated), and temperature and humidity conditions. The presence of ionic impurities (especially Cl^-) on the surface catalyzes the reaction of the migrating Cu and the oxygen or water present in the environment [13,14]. Thermal treatment applied to the package during assembly, testing and mounting at customer side all contributes to the enhancing of the corrosion kinetics, manifesting as discoloration on the NiPdAu surface.

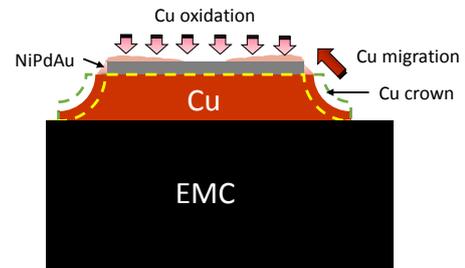


Fig. 6. Copper migration and subsequent oxidation resulting in discoloration.

IV. CONCLUSION

Copper migration and subsequent oxidation manifested as discoloration in the NiPdAu surface. SEM-EDS, TOF-SIMS and XPS results confirm the elevated concentration of Cu and O in the surface of discolored leads as compared with a good surface. The presence of ionic contaminants, especially Cl^- , possibly introduced due to handling, and oxygen and water due to exposure to environmental conditions resulted in the corrosion of the migrated copper on the surface.

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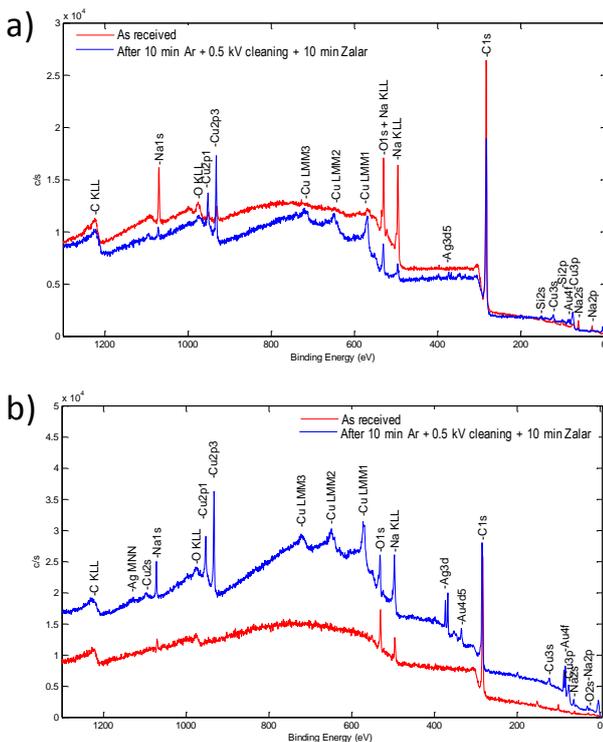


Fig. 5. XPS spectra of surfaces a) without and b) with discoloration in the as-received (red) and after sputter cleaning (blue) states.



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