ABSTRACT

Corrosion-induced failure analysis of copper wire bonded packages

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Due to the demand of higher input-output density in the integrated circuit (IC) and the cost reduction, Cu has become the material of choice over Au in the wire bonded electronic package. Although high-quality Cu wire bonds can be achieved by modifying the bonding conditions and process parameters, the long-term service reliability of the Cu-Al ball-bond interface in humid condition remains a major concern, especially to the automobile industry. At the Cu-Al ball-bond interface, two thin layers of intermetallics, Cu₉Al₄ and CuAl₂, are sandwiched between the Cu wire and Al pad. Accelerated humidity reliability tests showed Cu₉Al₄ disappeared, while Cu, CuAl₂, and Al remained. The disappearance of Cu₉Al₄ cannot be simply explained based on the nobility ranking of the metallic entities present. This dissertation focuses on fundamentally understanding the corrosion mechanism of the Cu-Al ball-bond interface and the corrosion-mitigating mechanism of current solutions from an electrochemical perspective.

Galvanic corrosion was considered as a major cause of bond failure due to the direct contact between dissimilar metallic entities at the ball-bond interface. Due to encapsulation, the galvanic
corrosion should occur in a thin layer of the electrolyte at the mold-bond interface initially. The high ohmic resistance of this thin-layer electrolyte may constrain the galvanic corrosion only at the contact interfaces between adjacent entities. Galvanic current density measurements showed the galvanic corrosion rate was higher between Cu₉Al₄ and CuAl₂ than those between Cu and Cu₉Al₄ as well as between CuAl₂ and Al. A crack should propagate faster along the interface between Cu₉Al₄ and CuAl₂. Due to the influx of Cu, CuAl₂ is slowly transformed to Cu₉Al₄. Voids form around the residual alumina sandwiched between Cu₉Al₄ and CuAl₂ due to the stress buildup and weak bonding strength between alumina and the intermetallics. These voids between Cu₉Al₄ and CuAl₂ can also facilitate the crack propagation. As electrolyte seeps into the crack and the ohmic resistance is reduce, part of the CuAl₂ adjacent to the crack zone will experience an increasing anodic polarization as imposed by a large area of Cu. The high anodic polarization can cause the crack to propagate further between Cu₉Al₄ and CuAl₂ until bond failure occurs. The failure separates Cu and Cu₉Al₄ from CuAl₂ and Al. For the Cu-Cu₉Al₄ couple, Cu₉Al₄ the anode should corrode much faster due to the strong galvanic effect imposed by a larger area of Cu. For the CuAl₂-Al couple, Al the anode should not be affected since the galvanic effect imposed by a small area of CuAl₂ is weak. Therefore, Cu₉Al₄ appears to corrode faster than Cu, CuAl₂, and Al.

Two major corrosion-mitigating methods are using Pd-coated Cu wire and "green" molding compound with a low chloride concentration. Galvanic current density measurements showed that reducing the chloride concentration lowered the galvanic corrosion rate between Cu₉Al₄ and CuAl₂ due to a lower anodic dissolution rate of CuAl₂. On the contrary, Pd addition increased the galvanic corrosion rate between Cu₉Al₄ and CuAl₂ due to a higher cathodic activity of Cu₉Al₄. But, Pd reduces the intermetallic growth rate and the associated internal stress buildup. The void
concentration at the Cu$_9$Al$_4$-CuAl$_2$ interface can be reduced. This can lead to a lower bond failure rate.