THE GOLD-EMBRITTLEMENT PHENOMENON IN ADVANCED ELECTRONIC PACKAGES AND ITS PREVENTION

ABSTRACT

Solder joints are the most vulnerable links in microelectronic devices. In fact, failure in solder joints is the most common root cause responsible for malfunction in electronic products. Therefore, improving the solder joints reliability is one of the most important tasks for electronic industry.

Gold-bearing finishes, such as the Au/Ni bi-layer, are extensively used in the electronic devices to protect the solderable pads against oxidation that can degrade the reliability of solder joints. After soldering, the surfaces Au will get into the solder and form many Au-bearing intermetallic particles, $(Au_{1-x}Ni_x)Sn_4$. Ductility loss of the solder due to the presence of these brittle $(Au_{1-x}Ni_x)Sn_4$ particles in the matrix is known as the "gold-embrittlement" [BAN1, DAE, DUC, ENW, FOS, GLA2, VIA, WIL]. Typically, the "gold-embrittlement" phenomenon occurres in the solder joint as the gold concentration is in excess of 3 wt.%. However, recent studies [BAN2, MEI2, MIY] reported that a different "gold-embrittlement" phenomenon could occur at a nominal Au concentration, which was much less than 3 wt.%. Instead of weakening the bulk solder, it deteriorated the solder/pad interface by forming a continuous $(Au_{1-x}Ni_x)Sn_4$ layer at the interface. This second phenomenon has become a critical issue in the electronic industry for many years. The objective of this thesis is to probe into the mechanism for this phenomenon and to find

approaches to inhibit this phenomenon.

In this thesis, it is established that the $(Au_{1-x}Ni_x)Sn_4$ was based on the $AuSn_4$ structure. It is proposed that the driving force for $(Au_{1-x}Ni_x)Sn_4$ to come back to the interface is to seek Ni to become more Ni-rich so that the Gibbs free energy can become smaller. Furthermore, this thesis suggests three techniques to avoid the formation of a brittle $(Au_{1-x}Ni_x)Sn_4$ layer at the interface. The first technique is to use a thinner gold in the surface finish so that the amounts of $(Au_{1-x}Ni_x)Sn_4$ formed is smaller. The second is to saturate the $AuSn_4$ with added Ni so that $AuSn_4$ does not have to go back to the interface for Ni. The third is to avoid the formation of $(Au_{1-x}Ni_x)Sn_4$ by adding a specific amount of Cu (0.5 wt.%) inside the joint. In fact, the doped Cu will form a more stable Cu_6Sn_5-based phase and force the Au atoms to dissolve into and trap by it, instead of forming the undesirable $(Au_{1-x}Ni_x)Sn_4$.

In the Appendix of this thesis, the strong effect of Cu on the interfacial reaction will be reported. We found that the structure of the intermetallic compound formed was very sensitive to a slight variation in the Cu concentration of solder joints. When the solder joints are Cu-free, the intermetallic compound had the crystal structure based on Ni_3Sn_4. With increasing Cu concentration, the reaction products changed from a Ni_3Sn_4-based compound into a Ni_3Sn_4-based compound plus a Cu_6Sn_5-based compound. When the Cu concentration increased even more, the reaction product became a Cu_6Sn_5-based compound. More importantly, it was found that the formation of Cu_6Sn_5-based compound at the interface could result in a lower Ni consumption rate. This reduction in Ni consumption suggests that a thinner Ni layer can be used with Cu-doped solder joints. Rationalizations for these effects were presented in the main text of Appendix A.