A Study on the Phase Equilibria and Interface Reactions between Nickel and Bismuth for Lead-Free Solders Applications

ABSTRACT

Two sets of experiments were carried out in this work. The first is the reaction between solid Ni and liquid Bi, and the second is the reaction between solid Ni and solid $NiBi_3$. Bismuth is an important ingredient in many electronic lead-free solders, while Ni is used in many Printed Circuit Board (PCB) and Ball Grid Array (BGA) package surface finishes.

In solid/liquid reaction, experiments were carried out at 300, 360, 420, and 480 ^oC for 10~360 minutes. It was found that a reaction zone formed between Ni and Bi. The reaction zone is a two-phase mixture of $NiBi_3$ needles dispersed in Bi matrix. The other intermetallic compound NiBi, which is thermodynamically stable at these temperatures, did not formed. In addition to the $NiBi_3$ formed within the reaction zone, $NiBi_3$ also formed outside the reaction zone as long needles with hexagonal cross-section. It is believed that these $NiBi_3$ needles formed during the solidification of liquid Bi. Reaction at 300 ^oC produced a thick reaction zone, and the thickness of the reaction zone increased rapidly with reaction time, reaching 400 μm after 360 minutes. Reactions at 360 ^oC and 420 ^oC produced very thin reaction zones. At high reaction temperatures, the amount of $NiBi_3$ outside the reaction zone increased rapidly. Nickel disk of 0.5 mm thick was fully dissolved into liquid Bi in 20 minutes. It is proposed that the formation of the reaction zone is controlled by two factors: the solubility limit and the diffusivity of Ni in liquid Bi. At higher temperature, both diffusivity and solubility limit are higher and tend to favor the formation of thin reaction zone.

In solid/solid reaction, experiments were carried out at 330, 370, 410, and 450 ^{o}C for 150~600 hours by using diffusion couples. It was found that NiBi with layered structure formed between Ni and $NiBi_3$. Analysis using EPMA showed NiBi has the composition of 51±0.7 at. % Bi. Although NiBi did not form when Bi was reacted with Ni, NiBi did form when Bi was reacted with $NiBi_3$ at 450 ^{o}C. This observation seems to indicate that nucleation of NiBi is not rate determining step, and the reason for the missing of NiBi is due to kinetics. The growth of NiBi layer was diffusion controlled with an activation energy of 84.4 kJ/mol. Marker experiment showed that both Bi and Ni atoms diffuse, but Bi atoms diffuse a little bit faster than Ni atoms.