

Fundamental issues of wetting and interfacial reactivity in electronic packaging

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3D integration is a modern way for electronic packaging where devices are stacked on top of each other or packaged. The electrical, optical and thermal connections are made between the stacks and package using interconnects. Soldering is the most common way of interconnecting electronic components and it is applied at all levels of integration in electronic packaging industry [1, 2].

Multiple reflows for solder/substrate contacts are widely used in 3D electronic packaging. During a reflow, several processes occur such as melting of the solder, wetting of the substrate by the liquid solder, interfacial reaction at the solder/substrate interface and solidification of unreacted solder. Each of these processes can play a crucial role on the subsequent evolution of the joint, and their control becomes more and more complex with the continuing trend towards increasing miniaturization.

Nowadays, copper is the most common conductor metal used in contact with solders owing to its good solderability characteristics. Commonly, in order to reduce the growth kinetics of intermetallic (IMC) layers at the liquid solder/Cu interface, a Ni barrier is introduced between Cu and the solder. Moreover, in order to protect Ni (or other metal) surface from oxidation, a thin Au layer is deposited on the metal surface. Sn-based solder alloys are the most popular lead-free solders used in the microelectronic packaging industry. However, for specific applications, other solder alloys are often used such as In based alloys or eutectic Au-Sn, Au-Si and Al-Ge alloys, etc.

A good wetting, contact angle well below 90°, is a necessary condition to obtain a good interfacial adhesion and therefore a good joint after the soldering process. The most common solder/metal substrate systems are reactive systems, i.e. with formation of fragile IMCs. Thus, the IMC layer formed at solder/substrate interface may adversely affect the mechanical properties of the joint. Moreover, this layer can play a major role on the undercooling degree of the liquid solder during the cooling process and thus on the final microstructure of the joint and its mechanical properties. Therefore, the morphology and thickness of the reaction layer should be controlled by monitoring the solder alloy composition and impurities, oven atmosphere, temperature and reaction time.

This presentation focus on the fundamental aspects of wetting and interfacial reactivity as well as on their interrelation during soldering process involving different solder alloys such as eutectic Au-Sn [3-5], Sn based alloys [6-16], eutectic Al-Ge [17], pure In [18] and different metal substrates such as Cu [6-10, 12, 15, 16], Ni [13, 14], Ag [11] and Au [3-5, 17, 18]. The relationship between wettability and reactivity in metal/metal systems is presented and discussed from a general point of view.

Wetting and spreading kinetics of metallic droplets on solid metal surfaces are studied by using the transferred drop technique in a metallic furnace under high vacuum ($P \sim 10^{-7}$ mbar) and a rapid camera (1500 frames/s). Figure 1 gives an example of variation of the contact angle and the drop base radius during spreading of liquid In on Au substrate at 300°C. In order to determine the different stages of the spreading kinetics (non reactive and reactive spreading regimes), specific experiments on the bulk IMC compounds are also performed. As an example, figure 2 compares spreading kinetics of liquid Sn on Cu substrate to that on a premade bulk Cu_6Sn_5 substrate. Finally, as usual metals are covered with thin native oxide layers which are not wetted by liquid metal alloys, the role of heat treatments at high temperature under vacuum and that of intense reactions occurring at the oxidized solid/liquid alloy interface on the final degree of wetting are presented and discussed.

In the second part of the presentation, we discuss some fundamental issues of interfacial reactions between different solder alloys and metal substrates in the light of specific experimental results. First, the role of the reaction product microstructure on the growth mechanisms and growth kinetics of IMC layers is clearly established by carrying out specific experiments. As an example, figure 3 compares the differences between the interfacial reactivity of Cu with the metastable Sn-0.7wt%Cu liquid alloy and Sn-0.7wt%Cu solid alloy at a rigorously identical temperature. Second, the evolution of the morphology and the average thickness of the reaction layer with time and experimental temperature is

presented and discussed for different solid/liquid diffusion couples - an example is given in figure 4 for Ni/liquid Sn system. Finally, the differences in the morphology and growth kinetics of the reaction layer at liquid solder alloy (A)/metal substrate (S) interface, due to the initial conditions of contact between them (immersion of solid S in liquid A or deposition of a layer of A on the surface of S), are highlighted on the basis of experimental results and microstructural analysis.

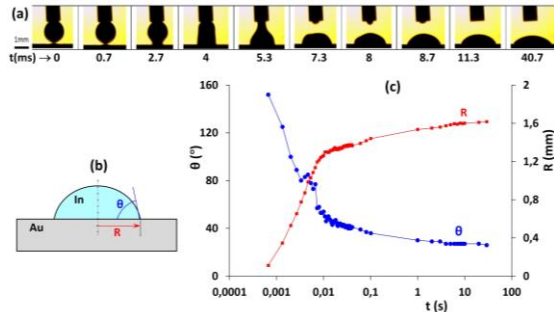


Figure 1 (a) Some images of In droplet during its spreading on Au at 300°C. (b) Definition of the contact angle θ and the drop base radius R. (c) Variation of θ and R during spreading.

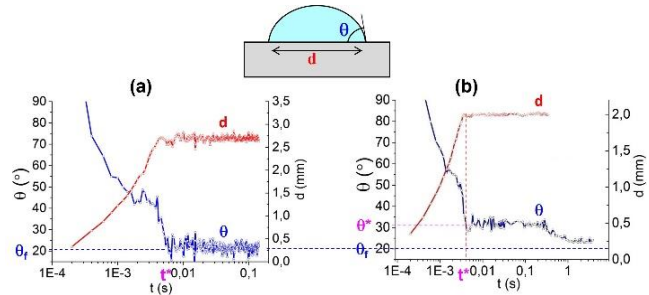


Figure 2 Variation of the contact angle θ and the drop base diameter d of Sn-7.8wt%Cu droplet during its spreading on Cu_6Sn_5 (a) and Cu (b) substrates at 390°C.

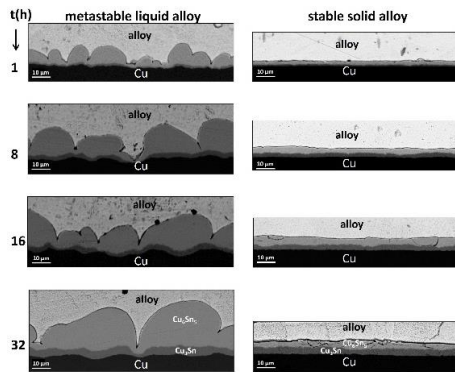


Figure 3 SEM micrographs of the reaction product formed at Cu/metastable liquid Sn-0.7wt%Cu alloy and Cu/solid Sn-0.7wt%Cu alloy interfaces for 1 to 32 h at 222°C.

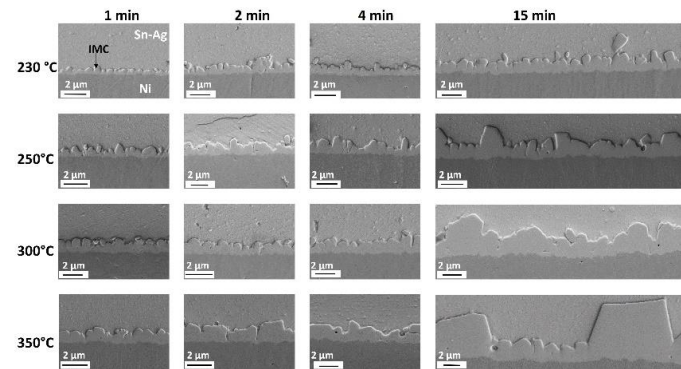


Figure 4 SEM micrographs of the reaction product formed at the Ni/liquid Sn-2wt%Ag interface for the samples aged for 1 to 15 min at 230 to 350°C.

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