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Cu–Al intermetallic compound investigation using *ex-situ* post annealing and *in-situ* annealing

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ABSTRACT

In Cu wire technology, it is observed that the Cu–Al IMC formation increases from a very thin layer of a few nm to a few μm after subjected to annealing process. The identified IMC phases are mainly $CuAl_2$, CuAl and Cu_9Al_4, whereas the other three phases which are less reported are Cu_4Al_3, Cu_3Al_2 and Cu_3Al. The reliability risk of Cu–Al IMC is commonly known, with the degradation of voids or crack propagation from ball periphery to internal ball bond direction after long duration of annealing. However, the cause of the degradation is not well established. This paper will focus on the study of the degradation of Cu–Al IMC layers with and without the presence of a mold compound by using *ex-situ* post annealing and *in-situ* annealing method on the same assembled sample. The *ex-situ* post annealing sample is studied using focus ion beam (FIB) after the molded sample had underwent a standard High Temperature Storage (HTS) at 150 °C for 1000 h. The *in-situ* annealing sample is studied using a transmission electron microscope (TEM) on a lamella with Cu–Al interface but without the presence of a mold compound. The result shows that the IMC formed are identified as $CuAl_2$, CuAl and Cu_9Al_4 *via* Energy Dispersive Spectrometer (EDX). These IMC are seen to grow increasingly with the duration of annealing process for both methods. The native Al oxide lines are seen for both methods and were embedded in between the IMC. The degradation starts at the ball periphery with cracks and voids at IMC are seen for the *ex-situ* postannealing sample but it is not observed under *in-situ* annealing sample. It is found that the degradation of the IMC is not caused by propagation of microcrack; instead it is assumed to be the influence of additive within the mold compound itself.

1. Introduction

In the early years, the Cu–Al IMC was investigated using friction welding method on a bulk copper and Al. Researchers have reported the formation of IMC phase after subsequent annealing [1,2]. Later, the subject gained major interest when the Cu wire is introduced as a replacement candidate to Au wire for interconnections to the Al bond pad for semiconductor integrated circuits. However, initial research shows that there are no IMC formations between the two interfaces as-bonded condition [3–6]. Until the emergence of recent technology advanced equipment such as high resolution scanning electron microscope (HRSEM) and FIB, researchers are able to conduct a thorough research to further investigate these interfaces. Researchers then reported the detection of a thin IMC layer that is few nm in thickness [7,8] as-bonded condition and continued to grow in thickness proportionally to the annealing process. With the aid of TEM, researchers are now able to examine the Cu–Al IMC formations in detail and its related phenomena that cause major IMC degradation, in which led to wire bonding failures [9,10].

Once the Cu wire is bonded onto the Al metal bond pad, diffusion between Cu and Al occurs where the atoms of two metals will move and interchange to form metallic alloys. According to the Cu–Al phase diagram [11], Cu–Al alloy consists of few IMC phases as per the phase diagram in Fig. 1, $CuAl_2(\theta)$, $CuAl(\eta2)$, $Cu_4Al_3(\zeta2)$, $Cu_3Al_2(\delta)$, $Cu_9Al_4(\gamma1)$ and Cu_3Al $(\alpha2)$. Among these phases, the most common that is being reported by others work are the $CuAl_2$, CuAl and Cu_9Al_4 [12–14] as these are the dominant phases that is easily detected using Energy Dispersive X-ray Spectrometer (EDX) system. The least reported by many researchers phases are the Cu_4Al_3, Cu_3Al_2 and Cu_3Al [8,15,16] due to the characteristics of these phases that rapidly transformed into another stable phases. In addition, these phases only appear as a very small island in overall IMC layer that is often hard to distinguish with other phases. Meanwhile, there are works that reports on the degradation and voids formation at the Cu–Al phases. Among them are cracks that start from ball periphery that propagates towards center direction of the ball bond [17,18], the Kirkendall voids between the IMC phases [19,20] and the Al oxide line [21]. Most of the studies have reported that the degradation are related to bonding process parameter [17], residue stress and intrinsic stress of IMC [18] or fully consumed Al pad with more Cu-rich phases that degrade the IMC [19]. However, it is noticed the data provided is not conclusive towards the understanding of the

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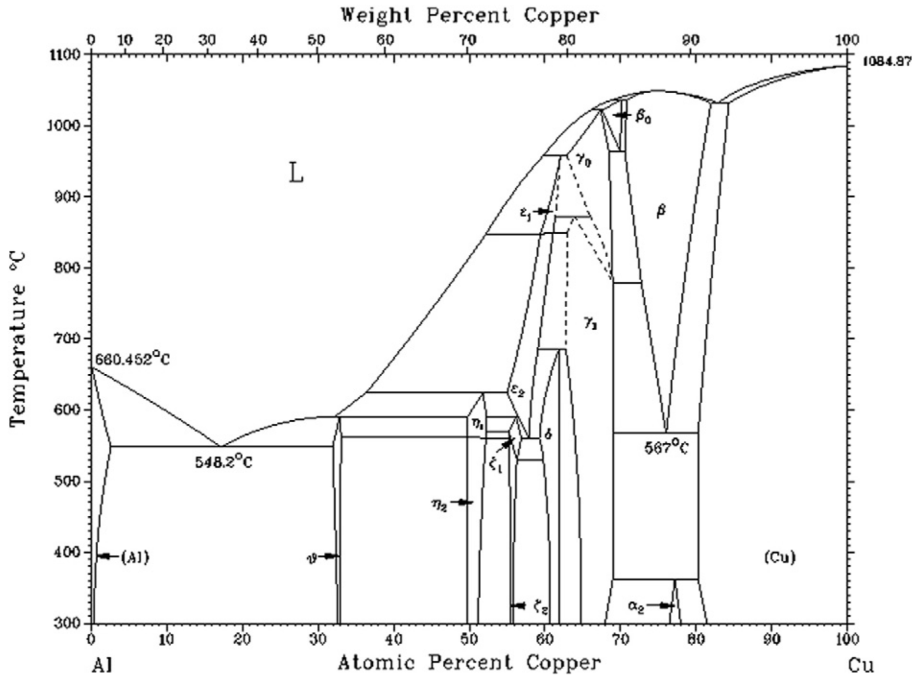

Fig. 1. Cu–Al phase diagram.

root cause of the degradation. Therefore, it is necessary to investigate on any other possible influence, such as the mold compound material used in a full assembled semiconductor device package. In this paper, we investigate the Cu–Al IMC growth behavior and degradation at IMC using an *ex-situ* postannealing and *in-situ* annealing method. The experimental results and its observations are as discussed in the following sections.

2. Experimental

In this study, pure Cu wire with a diameter of 22 μm is thermosonically bonded to a 1.5 μm thick AlSiCu metallization pad. The wire bonder is installed with a copper wire kit to prevent free air ball (FAB) oxidation. The process parameters are controlled with bond force set at 25–35 gf, ultrasonic power at 120–150 with transducer frequency used at 120 kHz and bond temperature at 180 °C with additional preultrasonic power of 50. The sample is then encapsulated with green compound.

The experiment is divided into two groups of samples. Group A is an *ex-situ* postannealing samples. It was subjected to HTS at 150 °C for a sequential duration of 100, 250, 500 and 1000 h respectively. A postannealing investigation is carried out by sectioning the samples along the ball bond interface perpendicular to bond ultrasonic direction. It is then followed by FIB cut at 30° to view the IMC at the center of the ball bond as shown in Fig. 2. A total of 3 ball bonds for each stress interval are investigated under FIB. The FIB images are then analyzed to investigate on any microstructural changes and the energy dispersive X-ray Spectrometer (EDX) were used to identify the IMC phases.

Group B is an *in-situ* annealing samples. It is the same molded sample used in *ex-situ* but has isolated the mold compound. It is prepared by micro-sectioning the molded sample along the ball center using conventional Silicon Carbide (SiC) rough abrasive grinding paper and then followed by using fine abrasive polishing method. Next, we prepare the lamella using FIB dual beam as shown in Fig. 3. The lamella preparation is targeted at the ball bond location near to the ball periphery. It is thin down to less than 100 nm thickness for an *in-situ* inspection using FEI Tital image aberration corrected TEM 80–300 with an acceleration voltage of 300 keV. The sample was clamped on Gatan 628 single tilt heating holder and loaded into the TEM chamber. The

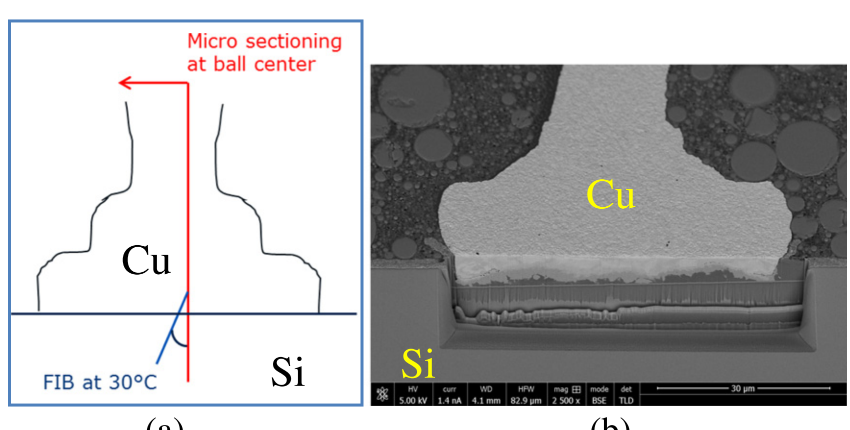

Fig. 2. Sample preparation for group A. (a) Schematic diagram of the microsectioning direction at ball center followed by FIB cut at 30 °C. (b) FIB overview at the entire ball interface after FIB cut.