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Effect of temperature on interface diffusion in micro solder joint under current stressing

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Abstract: The effects of temperature on Cu pad consumption and intermetallic compound (IMC) growth were investigated under current stressing. The Cu/Sn−3.0Ag−0.5Cu (SAC305)/Cu solder joints were used, with a certain current density of 0.76×10^4 A/cm^2 at 100, 140, 160 and 180 °C. The constitutive equations of cathode Cu pad consumption and anode interface IMC growth are established, respectively, based on the loading time and sample temperature. The cathode Cu pad consumption (δ) increases linearly with the loading time and the consumption rate shows parabolic curve relationships with sample temperature. The anode interface IMC thickness (δ_1) increased is linearly with the square root of loading time and the interface IMC growth coefficient shows parabolic curve relationship with sample temperature. The δ and δ_1 have different variation laws under current stressing, due to the current facilitating larger amount of IMC formation in the bulk solder.

Key words: electromigration; element diffusion; intermetallic compounds; Cu pad consumption

1 Introduction

The trend of miniaturization and the pursuit of greater performance in the microelectronics industry lead to a significant increase of the current density in micro solder joints. Electromigration (EM) has been a key and persistent reliability problem in micro-electronic technology, due to high current density in the micro solder joints [1−3]. The EM accompanies with the growth of anode IMC and the consumption of cathode pad, and both of them can lead to the solder joint failure owing to the decrease of mechanical properties and electrical properties [4−6].

Some studies showed that anode interfacial IMC thickness increased linearly with the square root of time [7−9]. CHAO et al [10] showed that the thickness of anode IMC layer increased linearly with the time. The IMC growth was faster at the higher current density or temperature during EM [11]. The fast dissolution of Cu and Ni was found at the cathode within the μBGA package [12]. The consumed thickness of Cu pads increased with the decrease of initial Cu concentration and the increase of soldering volume [13].

From the above, a number of researches [7−13] reported that the EM impacted on interface IMC growth and soldering pad consumption; however, each of research results is inconsistent and the influence rules of temperature on the consumption of Cu pad and the growth of IMC remain unidentified. Thus, it is necessary to establish the constitutive equation of the cathode consumption pad and the anode interface IMC growth under current stressing, for which has significant meaning on the EM test and electronic components life prediction.

In this work, the cathode Cu pad consumption and anode interface IMC growth were investigated at different temperatures. The constitutive equation of cathode Cu pad consumption and anode interface IMC growth were established, respectively, based on the loading time and sample temperature. Meanwhile, the reason of different variation rules between pad consumption and IMC growth during current stressing was analyzed.

2 Experimental

In this work, the solder joints Cu/Sn−3.0Ag−0.5Cu (SAC305)/Cu were used. The schematic diagram of test sample is shown in Fig. 1. The diameter of the solder

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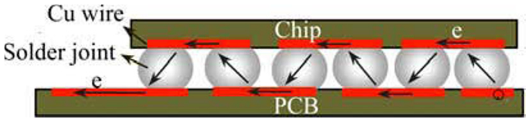

Fig. 1 Schematic diagram of test sample

joint was 400 μm, the opening diameter of the contact window to the solder was 310 μm, and the Cu wire had a thickness of 70 μm. The samples were prepared by reflow in a hot-air convective reflow oven. The peak temperature was 265 °C, and the sample was kept at the peak temperature for 30 s. The first reflow was carried out to solder the solder joints on simulate chip, and the second reflow was carried out to assemble the simulate chip and simulate printed circuit board (PCB). Figure 2 shows the microstructure of solder joint after reflow.

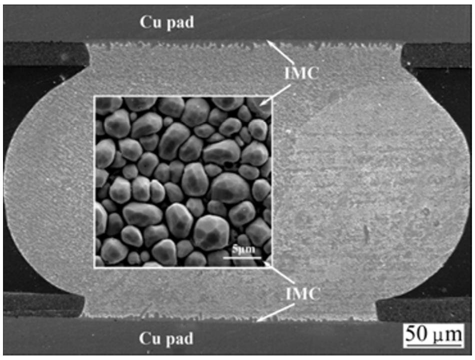

Fig.2 Cu/SAC305/Cu solder joint and IMC morphology after reflowing

In order to ensure a stable temperature of the specimen during the test, a virtual test system built by NI Compact DAQ platform combining with NI−9213 temperature module was used to monitor the temperature of the test. The first group of samples was carried by EM test. Testing current was set as 5.7 A, which produced a current density of 0.76×10^4 A/cm^2. Under the combined effect of Joule heating and furnace, the specimen temperature was maintained at 100, 140, 160 and 180 °C, respectively, for 25, 50, 100 and 200 h. The second group of samples was sustained thermal aging test (160 °C) to obtain Cu pad consumption and interface IMC growth in thermal aging process. In this test, twenty-four solder joints were used under the same test condition. The average of consumption Cu pad and thickness of IMC were calculated by dividing the area of IMC by the length of interface. Deep-etching method was performed to observe the 3D morphology of the IMC.

3 Results and discussion

3.1 Cu pad consumption and IMC growth during thermal aging

After reflow, a thin layer Cu_6Sn_5 is formed between Cu pad and SAC305 solder, and a small amount of Cu pads are consumed, as shown in Fig. 2. The Cu_6Sn_5 shows bump–like appearance. The thickness of Cu_6Sn_5 is about 5.72 μm and the consumption of Cu pad is about 2.75 μm. Figure 3 shows the micrograph of solder joint after thermal aging at 160 °C for 200 h. After thermal aging, Cu_6Sn_5 shows layer-type morphology and the grain size of Cu_6Sn_5 increases, meanwhile, a layer of Cu_3Sn forms between Cu_6Sn_5 and Cu pad. Figure 4 shows the thicknesses of interface IMC (Cu_6Sn_5+ Cu_3Sn) and the Cu pad consumption vs the annealing time. As the aging time rises, both the thickness of interface IMC and the consumption of Cu pad increase. The kinetics of IMC growth obeys the parabolic-growth law, which indicates that the formation of IMC is a diffusion-controlled reaction. The growth kinetic matches well with that reported by ONISHI and FUJIBUCHI [14]. The consumption of Cu pad has similar variation law with the growth of IMC, as shown in Fig. 4. The main reason is that Cu pad reaction with Sn formed Cu_6Sn_5 at the Cu−solder interface, so the consumption of Cu pad and the growth of IMC have close relation and similar rule.

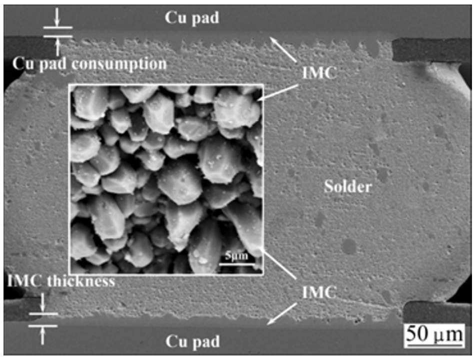

Fig. 3 IMC growth, Cu pad consumption and IMC morphology after thermal aging at 160 °C for 200 h

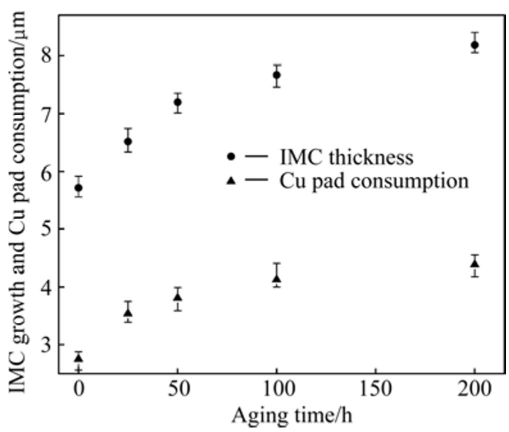

Fig. 4 IMC thickness and Cu pad consumption under thermal aging at 160 °C after different aging time

3.2 Cu pad consumption and IMC growth under current stressing at different temperatures

The microstructure of solder joint stressed with