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EFFECTS OF THERMAL AGING ON INTERMETALLIC COMPOUNDS AND VOIDS FORMATION IN AuAl WIRE BONDING

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ABSTRACT

There are several issues related to the mechanical and electrical wirebond failure during wirebonding process. Major factors are associated with AuAl intermetallic system. AuAl intermetallic compounds (IMC) can easily form at room temperature and can be accelerated with the elevated temperature. In this paper, pattern of intermetallic compounds growth and potential degradation due to voids in thermosonic ball bonding were studied on AuAl intermetallic compounds. The thermosonic ball bonding process used 99.99% gold wire and aluminized pad of Si chip. Results after HTS at 150ºC for 500 hours demonstrated that voids were generated around the diffusion layer because of the Kirkendall effect and severe voids was clearly exhibited after thermal aging at 150ºC for 1000 hours. Prolong aging time can lead to bonding failure associate with Kirkendall voids.

INTRODUCTION

AuAl intermetallic compounds is describes as intermediate alloy that present at the bonded interface of Au bonding wire and aluminized pads of a Si chip by diffusion welding. The intermetallic compounds growth via crystal vacancies made available by defects, contamination, impurities, grain boundaries and mechanical stress. With time and temperature the AuAl intermetallic compounds advance the Kirkendall voids and degrade the long-term reliability of AuAl bonding system. This is generally accepted as the cause of bond failure influenced by the different diffusion rates of Au and Al atoms through intermetallic phase layers [1].

AuAl Intermetallic Compounds Formation

Observations suggest that the initial growth rate of the AuAl intermetallic compounds usually follows a parabolic relationship:

$$x = K t^{1/2} \tag{1}$$

where x is the intermetallic layer thickness, t is the time, K is the rate constant and:

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$$K = \mathrm{C}\, e^{-E/KT} \qquad (2)$$

where C is a constant, E is the activation energy for layer growth (in electron volts), k is the Boltzman constant, and T is the absolute temperature [2].

The phase diagram of the Au-Al alloy system exhibits five intermetallic compounds as shown in Figure 1. Detail study on the intermetallic compounds have been done by Philofsky [3] with Au_5Al_2 (tan), Au_4Al (tan), Au_2Al (metallic gray), AuAl (white) and $AuAl_2$ (deep purple) intermetallic phase being observed. It is apparent that Au_5Al_2 grows much faster than the other phases and often associated with the bond failures.

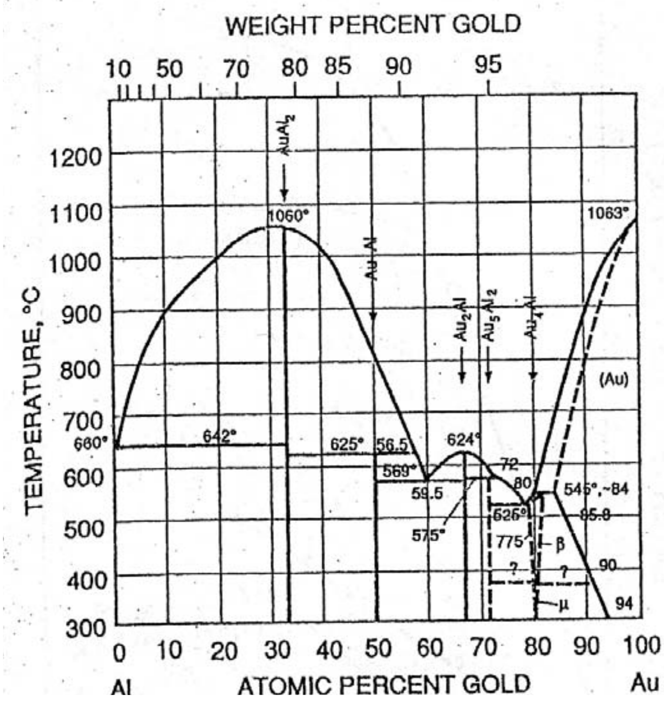

Figure 1: Al-Au phase diagram taken from Hansen“Constitution of Binary Alloys” [4].

EXPERIMENTAL METHOD

Samples for this test were prepared with a 120kHz Kulicke & Soffa 8028 thermosonic wire bonder using 25 µm gold (99.99% Au) wire. Bonding parameter setup was carried out on bond pads with an opening of 90 µm and constant bonding temperature of 200°C. Optimized parameter setting have been used for this purpose, where optimization of the parameter was performed using the standard method of response surfaces. Bonded samples were then molded with a commercial molding compound.

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Molded units have undergone high temperature storage (HTS) at 150ºC in air environment for 500 hours and 1000 hours. Decapsulation process were carried out on the molded units before measuring the ball bond strength by pull and shear test using DAGE 4000 series pull and shear tester.

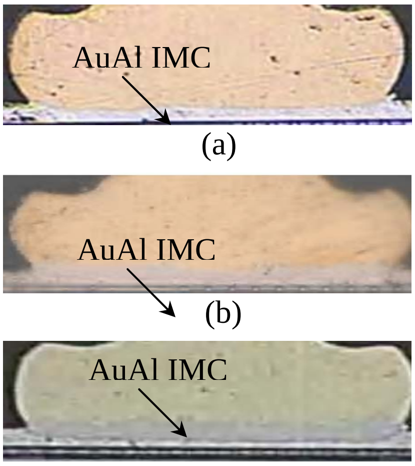
Samples were then mounted in a low heat epoxy, and were wet-ground with small grit size of 1,200 paper until the gold wires observed, then polished with 6 µm, 3 µm, 1 µm and 0.25 µm diamond suspension on silk clothes. Observation on the microstructure was made using scanning electron microscope (SEM) and elemental analysis was performed by energy dispersive X-ray (EDX) technique to detect the present of oxygen at the degrade intermetallic phase.

High Temperature Storage Life

High temperature storage method typically was used to determine the thermal activated failure mechanisms based on the JEDEC standard EIA/JESD22-A103C, which was capable to test the ball bonds of various wire diameters. The molded units were subjected to continuous storage temperature of 150(-0/+10)°C.

RESULTS AND DISCUSSION

During aging, a typical voids formation at 150ºC for 500 hours and 1000 hours were observed. AuAl intermetallic compounds layer was clearly visible as a thin uniform layer for as bonded ball and growth for a few micron thick after prolong aging. The thickness of the intermetallic layer was observed to increase dependent on time and temperature as shown in Figure 2(a) - (c).



(a)

(b)

(c)

Figure 2: Microstructures of ball bond: (a) as bonded ball, (b) after HTS at 150ºC for 500 hours, (c) after HTS at 150ºC for 1000 hours.

The as-bonded of unetched cross-section samples showed that the intermetallic compound was form as a thin layer and present strong ball bond. However, close-up of optical image had demonstrated the little formation of Kirkendall void reveals at the void spot as shown in Figure 3. Chang *et al.* [1] described that passive regions on the aluminum bond pad before wire bonding largely influenced for initial voids. In this case the diffusion barriers will be created by the passive regions and act as a barrier for the Au and Al inter-diffusion.

After 500 hours the intermetallic compounds layer were demonstrated to grow vertically and laterally into the Au ball. At this time, the AuAl intermetallic phase showed well developed with no heavy degradation line due severe voids formation although some void spots were observed as shown in Figure 4.

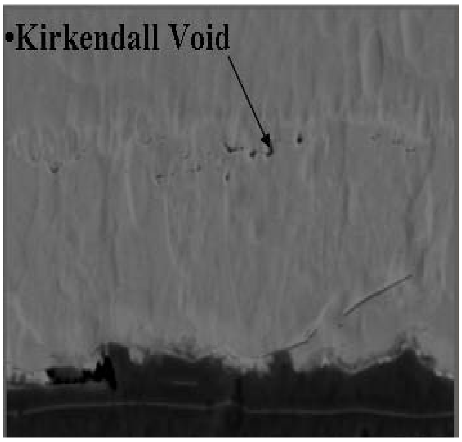


Figure 3: Little Kirkendall void occur at 0 hours.

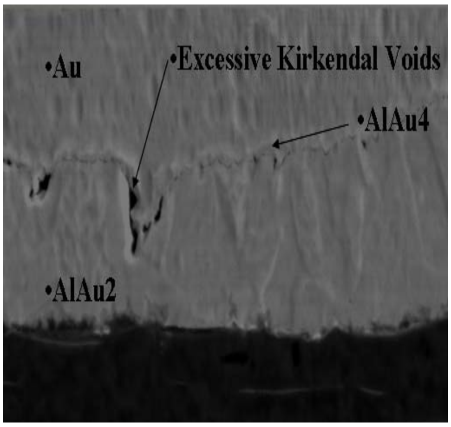


Figure 4: Some separated degraded spots due to voids formation were observed at HTS 150ºC 500 hours.

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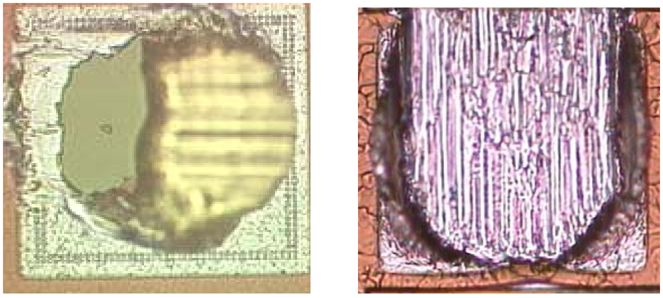
It is clearly indicated that the AuAl intermetallic compounds quickly grow into the Au ball, while the growth rate into Al is relatively low. The more AuAl intermetallic compounds that are moving around at different rates, the more voids and failures will be observed. Murali et al. [5] reports further heating causes Au to diffuse into the diffusion layer to formed Au_4Al on the Au ball side and voids are generated around the diffusion layer because of the Kirkendall effect caused by the difference in the diffusion velocity between gold and aluminum. Measurement using shear test machine showed that the bonded shear results after aging at 150ºC for 500 hours were all above the specification as shown in Figure 5.

Figure 5: Ball shear results after aging at 150ºC for 500 hours.

Visual inspection by optical microscope on the shear failure mode indicated that 99% of the failure mode exhibit visible traces of gold or metallization (code 2) and 1% bonded ball sheared through more than 50% of the contact area (code 1). Figure 6 shows the failure mode images for code 1 and code 2.



(a) (b)

Figure 6: Bonded ball shear failure mode for (a) code 1 and (b) Code 2.

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In Figure 7, severe Kirkendall voids formation and separation line of Kirkendall voids developed against the front phase of Au_4Al were visible after aging for 1000 hours. This phenomena causes a separation of bonding area from the neighbouring Au layer that advanced by Kirkendall voids and can resulting in a ball bond lift failure mechanism. However from this study there is no observation of ball lift. Although severe Kirkendal voids observed, complete degradation and mechanical separation line were not observed.

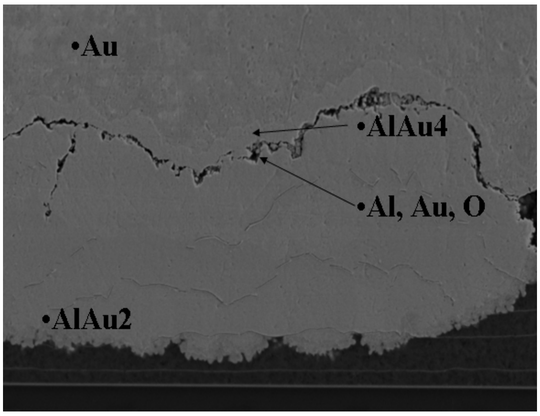

Figure 7: Severe voids formation reveals after HTS 150ºC 1000 hours.

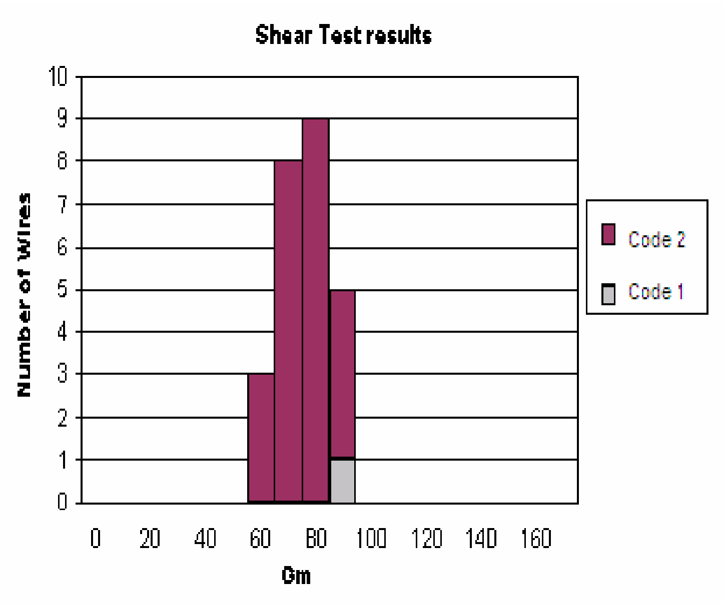

Figure 8: Ball shear results after aging at 150ºC for 1000 hours.

The shear test at this temperature condition showed almost the same percentage of failure mode as present after aging at 150ºC for 500 hours. A comparison of shear strength for both aging condition present a slight decrease after aging for 1000

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hours, however the wirebonding reliability test results were favorable as shown in Figure 8. Dittmer *et al.* [6] discussed that, the concentration of these voids does not weaken the bond or indicate complete fracture significantly, therefore the failure mode of the shear test do not exhibit any ball lift failure although some severe formation of Kirkendall voids were observed.

A device will be considered a high temperature storage failure if mechanical damage such as completed fracture line and heavy Kirkendall voids were formed in the AuAl intermetallic compounds region. The diffusion and reaction is continuous. This phenomenon will create more numbers of different diffusion rates of either Au-through-Al or Al-through-Au. Physically they are caused by a net current of atoms diffusion into neighbouring places. The lack of atoms on one side is balanced by voids.

CONCLUSION

AuAl intermetallic compounds grow continuously with temperature and time. Initial degradation activated by rapid formation of Kirkendall voids at the Au-AuAl interface and subsequently was observed to rise from 500 hours to 1000 hours at 150°C. Decreasing in shear strength for 1000 hours aging can be explained due to the presence of severe formation of Kirkendall voids, which has been observed from microstructural study.

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