Solid State Science and Technology, Vol. 16, No 2 (2008) 173-179
ISSN 0128-7389

EFFECT OF ULTRASONIC ENERGY AND FORCE ON INTERMETALLIC GROWTH PATTERNS FOR 2N GOLD WIRE

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ABSTRACT

Intermetallic formation between gold wire and Al pad is well documented to represent mechanical strength of ballbond. Bonding achieved when these two metals come into intimate contact between each other by interactions of ultrasonic energy, force, temperature and time. Under elevated temperature and time, theoretically the intermetallic phase can thicken and growth due reactive diffusion activated by temperature. This paper presents effects on ultrasonic energy and force to the intermetallic growth patterns for gold wire with 99% composition of Au. Samples were prepared by different variables of ultrasonic energy and force with constants bonding temperature at 240°C. Investigation was carried out by baking the samples in the high thermal storage (HTS) chamber at 175 °C. Measurements for ballbond mechanical strength and observations on intermetallic growth patterns were carried out using ball shear and ball pull tester, optical microscope and scanning electron microscope (SEM). The results showed that, variables of ultrasonic energy and force at elevated time of HTS play significant influence to the intermetallic growth patterns and bonding strength.

INTRODUCTION

Thermosonic wire bonding has been widely applied in the semiconductor packaging industries to connect the integrated circuit (IC) chips to the leadframes. Gold wires with 99.99% purities are preferred interconnect material, but the need to retard the intermetallic growth as well as reliability concern had made gold wires with 99% purities as a preferred alternative. During initial bonding cycle, end of the wire is melted into a ball using an electric arc on a wirebonding machine and the ball is then thermosonically welded to the die pad metallization which is usually 0.7-1.0µm of Al [1] with minor additions of Cu (typically 0.5 wt.%) and/or Si (typically 1 wt.%) [2].

Intermetallics are formed primarily between Au and Al, although the minor elements Cu and Si must be accommodated within the intermetallic phases. From Au–Al phase diagram, the equilibrium phases such as Au_2Al, $AuAl_2$, AuAl, Au_5Al_2, Au_8Al_3, Au_3Al_2, and Au_4Al are exist. However, under continuous thermal exposure, diffusional process especially through the low melting-point compounds take place [3]. Ultrasonic energy, pressure, temperature and time are well known as critical

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factors that lead to the Au-Al intermetallic formation. Correlation between these factors and the growth patterns of Au-Al have been studied by Jun-hui et. al [4], whom point out that, for constant force and time, the ridged area of the bond pattern increases when more power is applied. For constant force and power, the ridged location of the bonded region moves closer to the bond center with time. For constant power and time, the total area of the bond pattern increases in size with increasing load. This paper describes effect on ultrasonic energy and force to the initial formation of intermetallics during ball bonding and growth patterns of Au-Al intermetallics at certain elevated time of HTS for 2N gold wire. Further analysis on this case has been done by observing the coverage and growth patterns of the Au-Al intermetallic before and after thermal aging.

EXPERIMENTAL METHOD

A test vehicle has been used to study the effect of force and power to the initial formation of Au-Al intermetallics on the high temperature storage life of 2N gold wire bond. Four types of samples are assembled (Type A, B, C and D) with variables power and force for bonding setup. HTS life test has been performed on these samples at 175 °C for 384 hours. Measurements for ballbond strength were done by ball shear test using DAGE 5000. It was found that all samples passed the HTS test but performed low shear strength for sample D. This result was clearly observed after baking in the HTS test (Figure 1).

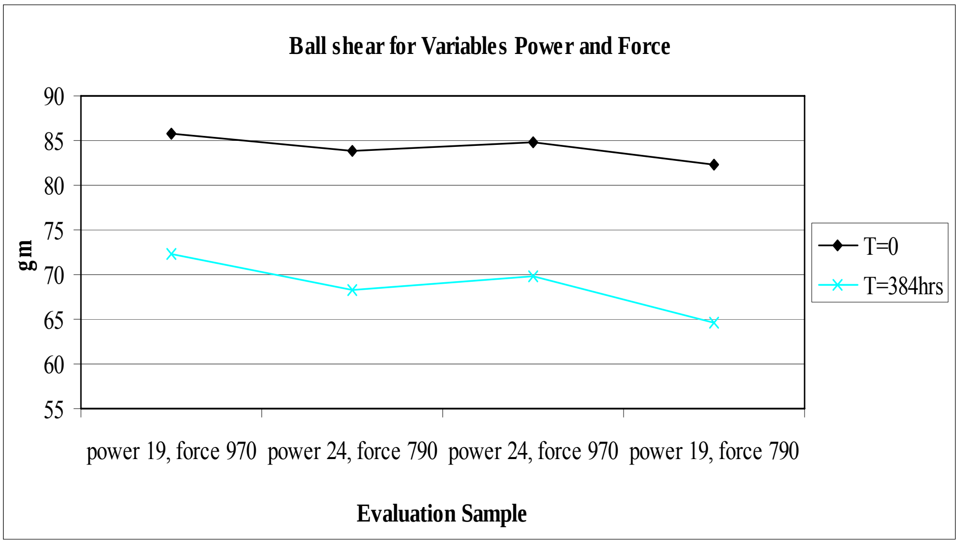

Figure 1: Shear strength for variables power and force before and after HTS test at 175 °C for 384 hours.

In order to understand this mechanism, observations on intermetallic patterns and coverage have been made to all the samples before and after HTS test. Samples were prepared with a 100 kHz Esec3006FX bonding model using 30μm gold (99% Au)

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wire. Bonding was performed with constant bonding temperature at 240ºC. While running the evaluation process, two factors were kept variables which include force (790 Nm and 970 Nm) and ultrasonic level (19% and 24%) for 1st bond, while parameter for the 2nd bond were kept constant. The matrix of the parameter variables are given in Table 1.

Table 1: Parameter matrix for 1st bond.

Evaluation Sample	1	2	3	4
Ultrasonic Level (%)	19	24	24	19
Force (Nm)	970	790	970	790

Bonding process were tuned for each evaluation to get optimize bonding performance by controlling the ball diameter, ball height and loop height within the control specification. The setup bonding temperature was also measured with a K-type thermocouple sensor. In order to assess thermal reliability as well as intermetallic growth patterns of the variables power and force, the samples were aged through high thermal storage test (HTS) at 175 ºC for 384 hours. Cross-section were prepared in the normal metallographic manner by taking care not to smear the soft gold across the bond pads while ensuring that the deformation layer, caused by polishing [2]. Firstly, samples were mounted with a commercial epoxy and stored for curing. Cured samples were wet-ground with small grit size 1200 sand paper to see the whole ballbond. Polishing was then proceeded with 3, 1 and 0.25 µm diamond suspension on silk cloths.

Observations on the intermetallics coverage area underside of the bonded balls have been performed by scanning electron microscope (SEM) after removed the bonded balls. The method used to removed the bonded ball were referred on the method that used by Breach and Wulff [2]. The solution has been prepared by dissolved 3 g KOH pellets in 100 ml water, which was heated to 70 °C. Bonded specimens were placed into the solution for 20 min, and then rinsed with DI water.

RESULTS AND DISCUSSIONS

Intermetallic Coverage and Growth Patterns Before HTS

All samples before and after performed reliability test at 175 ºC for 384 hours indicated more than 70% of the intermetallic coverage for all ballbonds. Results from SEM indicate variables power and force have resulted to the variables level of coverage. There is connectivity between the intermetallic regions and spaces where the ball has not been bonded to the Al pad metal [2]. Intermetallic coverage can influence the bonding reliability as well as to determine the diffusion reaction in the Au-Al system that affect by bonding parameters setup. Figure 2 shows coverage area underside of the bonded ball before HTS for (a) power 19% and force 970 Nm (b) power 24% and force 790 Nm (c) power 24% and force 970 Nm (d) power 19% and force 790 Nm.

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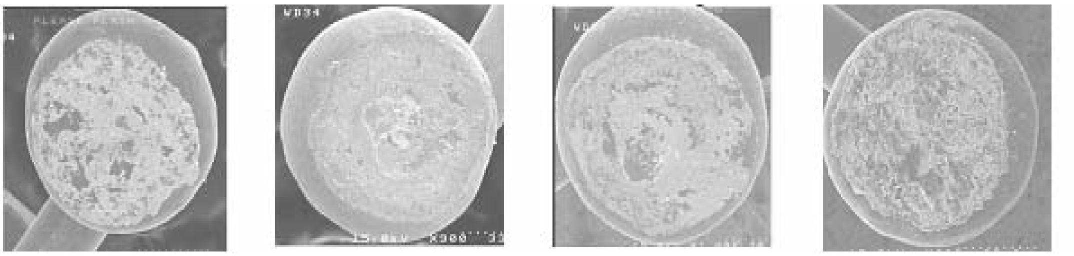
Close up on the underside of the ball bonds demonstrates uniform intermetallic coverage due to higher force applied. The higher the load, has forced the Au and Al to come into intimate contact and results on the increasing of the total coverage area. Lack of force gave non-uniform bonded region especially at the center of the ball as shown from sample B and lack of intermetallic coverage for sample D compared to others. The higher the power the bonded region increase significantly. This result is in good agreement with Breach and Wulff [2] and Murali [5] whereby applied compressive force maintain proximity between the joining surfaces and increasing in load has resulted in the increasing of the size for the total area of the bond pattern. The higher ultrasonic energy cause severe deformation (bulk atom flows) and alter the shape of the wire bond and has resulted in the increasing of the ridged area of the bond pattern.



(a) (b) (c) (d)

Figure 2: SEM image of the underside of a typical gold ball after removal from a bondpad without HTS test: (a) power 19% and force 970 Nm, (b) power 24% and force 790 Nm, (c) power 24% and force 970 Nm, (d) power 19% and force 790 Nm.

Figure 3 shows that the intermetallic compound has been observed to grow into the Al pad but only within the interfacial contact gold, while non intermetallic was observed to grow within the edge of the bonded ball.

(a) (b) (c) (d)

Figure 3: Optical microscopy image of a typical gold ball cross-section without HTS test: (a) power 19% and force 970 Nm, (b) power 24% and force 790 Nm, (c) power 24% and force 970 Nm, (d) power 19% and force 790 Nm.

Observations by Harman [3] suggest that the initial growth rate of the intermetallic compounds usually follows a parabolic relationship:

$$x = K t^{1/2} \qquad (1)$$

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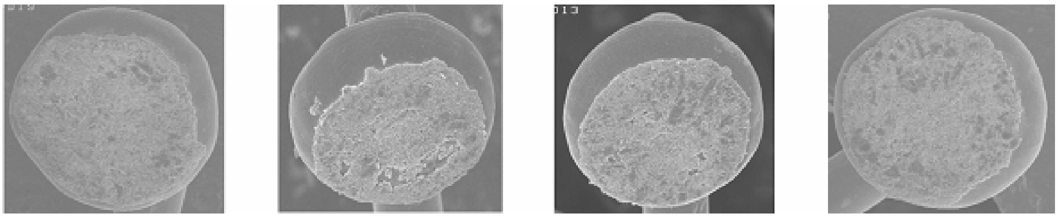
where x is the intermetallic layer thickness, *t* is the time, *K* is the rate constant and :

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

Where *C* is a constant, *E* is the activation energy for layer growth, k is the Boltzman constant and T is the absolute temperature. From the parabolic relations, intermetallic layer are tend to thicken with the increasing of temperature. Moreover, when temperature goes up, its soften the metal, accelerates the atom diffusion between different metals and enhanced the microstructure strength [6].

Intermetallic Coverage and Growth Patterns After HTS at 175 ºC for 384 Hours
Figure 4 shows that there is a large difference of Au-Al intermetallics distribution in gold area between the variables ultrasonic energy and force. Low coverage can result in strongly localized growth through relatively few contact points, leading to ‘spikes' of intermetallic, excessive void formation and significant deterioration of strength [2]. On the other hand, bonding with lower power and force had performed to the non-uniform of Au-Al intermetallic compound, while adequate power and force have been resulted to the uniform of Au-Al intermetallic growth patterns. Figure 5 shows the Au-Al intermetallic growth patterns through the cross-section of the bonded ball after HTS for sample A, B, C and D, respectively.



(a) (b) (c) (d)

Figure 4: SEM image of the underside of a typical gold ball after removal from a bondpad with HTS test at 175ºC for 384 hours: (a) power 19% and force 970 Nm, (b) power 24% and force 790 Nm, (c) power 24% and force 970 Nm, (d) power 19% and force 790 Nm.

(a) (b) (c) (d)

Figure 5: Optical microscopy image of a typical gold ball cross-section with HTS test at 175ºC for 384 hours (a) power 19% and force 970 Nm (b) power 24% and force 790 Nm (c) power 24% and force 970 Nm (d) power 19% and force 790 Nm.

Sample D shows unstable of Au-Al intermetallic cross-section result compared to sample A, B and C. This clearly demonstrate that combination of low force and power have presented to the poor weld between Au and Al. Numerical and

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experimental studied by Tee and Zhang [7] conclude that HTS life is much longer for the bond with uniform intermetallic compound than that with non-uniform intermetallic compound. Furthermore, in order solid-state diffusion to occur, high energy is required to squeeze most atoms or ions through perfect crystal structure by vacancy migration mechanism [8]. While ultrasonic vibration activates dislocations in the crystalline lattice and increases atomic diffusion, by supplying the activation energy for the diffusion process [4].

CONCLUSION

The morphology of Au-Al intermatellic coverage illustrate that bonding parameters such as power and force have significant effect to the formation of intermetallic compound. Un-optimized power and force may have resulted in poor weld between Au and Al. Therefore, achievement of uniform intermetallic coverage is one of the factors in determining the reliability of the wirebond. Achievement of stable intermetallic growth illustrate by cross-section, however, is not a guarantee of high coverage. This is because, cross-section images does not present the actual coverage area. Other method such as 3D imaging system may be needed for further analysis. Although details intermetallic phases were not characterised in this study, the changing in relative amounts of coverage with power and force presents important role to achieve robustness in wirebond.

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