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# Effect of Temperature on Deformation Characteristics of Gold Ball Bond in Au-Al Thermosonic Wire Bonding

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**Abstract**- Wire bonding is a process that is used to form solid-state bonds to interconnect metals such as gold wires to metalized pads deposited on silicon integrated circuits. Typically, there are 3 main wire bonding techniques; Thermo-compression, Ultrasonic and Thermosonic. This experiment utilizes thermosonic bonding which applies heat, ultrasonic energy and force on an Au-Al system. Sixteen groups of bonding conditions at various temperature settings were compared to establish the relationship between ball deformation and temperature. The results of this study will clearly indicate the effects of applied bonding temperature towards bond strength and deformation characteristics of gold ball bonding.

**Index Terms** - Gold ball bond, Intermetallic phase , Shear strength, Thermosonic wire bonding

## 1. Introduction

IN recent years, thermosonic wire bonding has been prevalent in the application of solid state inter-connect technology. In the process of making an interconnection, two wire bonds are formed. The first bond involves the formation of a ball with Electric Flame Off (EFO) process. The ball is placed in direct contact within the bond pad opening on the die. With application of load (bond force) and ultrasonic energy within a few milliseconds (bond time) under the influence of heat, a ball bond is formed at the aluminum bond pad. Factors such as ultrasonic energy, temperature, and pressure may influence the quality of bonding quality [1, 2].

Upon application of the primary factors to form an intermetallic layer that makes the connection on the bond pad of a die, the wire is the lifted to form a loop and then placed in contact with the desired bond area of a leadframe to form a wedge bond. In this process, the bonding temperature is one of the main bonding parameters which play an important role in the bonding [3]. Essentially, different temperature will lead to different bonding output response as different temperature conditions mean different bonding environment. In previous studies, a parabolic relationship between temperature and strength has been determined. Too low or too high temperature for bonding can lead to unsuccessful bonding or low bonding strength [4, 5].

Although many studies about temperature effect in wire bonding has been carried out, it is worth investigating the criticality of temperature application on thermosonic wire bonding while keeping other factors at constant. This study will be able to depict the actual deformation characteristics of Gold (Au) ball bond with respect to temperature, while keeping other bonding factors as constant. Sixteen groups of bonding data at various temperature settings were compared to establish the relationship between ball deformation and temperature.

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## 2. Experiment Method

Gold wire bonding was carried out using a 138 KHz Thermosonic wire bonder. The bonding temperature was tuned to produce different thermosonic bonding process while all other bonding parameters such as bonding ultrasonic power, bonding force and time were kept unchanged. The bonding parameters are listed in Table 1.

Table1: Bonding Parameters

| US Power (DAC) | Bond Force (gm) | Bond Time (ms) | Temperature (°C) |
|---|---|---|---|
| 48 | 28 | 15 | 40°C - 340°C |

The diameter of gold wire (99.99% Au) used is 1 mil. The gold wire bonding was performed on a 16mil x 16 mil die size with metal composition Al-99.5%, Cu-0.5%. The bond pad opening is 4mil x 4 mils and bond pad pitch is 5 mils.

The following is an outline of the gold wire bonding procedure which was carried out. Refer to Figure 1.

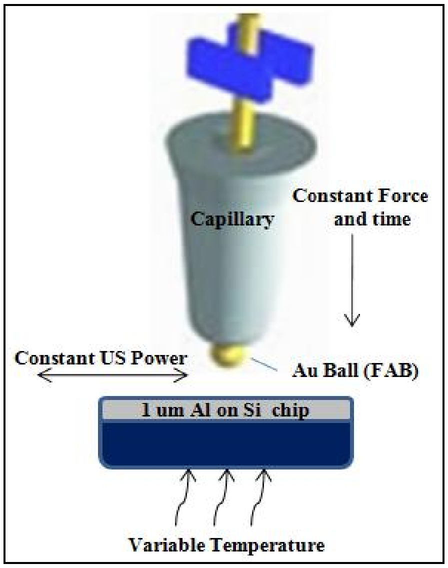


Fig.1. Thermosonic wire bonding setup

i. The Au wire at the capillary tip was melted to produce the Free air ball (FAB) using discharge from electric flame off (EFO)

ii. The capillary is lowered and the free air ball is compressed onto the Al pad for bonding.

iii. The capillary is lifted and the Au wire is connected to the lead to produce a wedge bond.

iv. The Au wire is cut.

Steps 1 – 4 are repeated.

The bonding temperature was measured by a K-type thermocouple sensor with a measurement range of 0 - 500°C. A total of 16 runs were performed with bonding temperature range of 40°C to 340°C with a step of 20°C.The bonding experiments were consistently repeated for 50 times under each testing condition for statistical analysis.

To assess the output response of the thermosonic bonding, the wire pull test and ball shear test are performed using Westbond wire pull tester and Royce 550 wire bond tester respectively. The destructive shear strength between the gold ball and substrate is a common judgment for bondability [6, 7].

To further analyze the bondability, intermetallic coverage assessment is also carried out using fuming potassium hydroxide, KOH. Cross sectioning using grinding and polishing machines were used to enable analysis on gold ball bond. Samples were observed using an optical microscope and scanning electron microscope (SEM). Thickness and diameter of the ball bond profile and Inter Metallic Coverage (IMC) growth was measured using micrometer scale attached to the optical microscope and the scope was calibrated using the standards provided with the scope.

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## 3. Result and Discussion

### I. Effect of Temperature on Bond Strength of Au-Al Wire Bonding

During the bonding process of Au and Al system in thermosonic system, the temperature plays a very important role. The relationship between bonding strength and temperature was successfully obtained from the experiment carried out and is in coherence with previous studies carried out [4, 5]. Results of relationship of shear strength and temperature are shown in Figure 2.

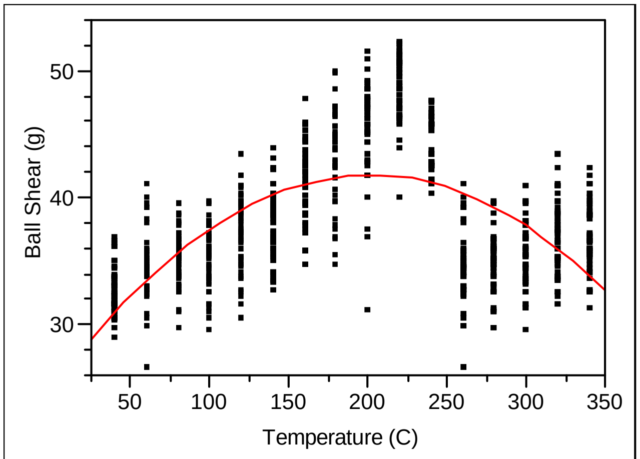
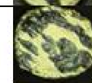
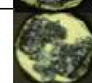
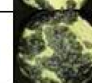
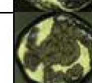
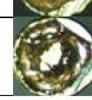



Fig 2: Shear strength against temperature

Statistical mean, standard deviations, process capability index of bonding strength and intermetallic coverage for each experimental temperature consisting of 50 tests each is listed in Table 2. IMC is distinguishable in its dark colored formation in Table 2. It is observed that too low or too high temperature may result in unfavorable bonding or low bonding strength. This experiment suggests that, the most suitable bonding temperature for Au and Al system is between 200°C and 240°C. This observable fact can be further explained by the following related theories [8, 9, and 10] and experiment:

Table 2: Bond strength response against temperature

| Temperature (°C) | Bonding Strength Response | | | | |
|---|---|---|---|---|---|
| | Ave (g) | St Dev | CpK | IMC | Approx. IMC % |
| 40 | 32.50 | 1.83 | 2.28 |  | 50 |
| 60 | 34.23 | 2.70 | 1.76 |  | 50 |
| 80 | 35.09 | 2.02 | 2.48 |  | 50 |
| 100 | 35.22 | 2.38 | 2.13 |  | 50 |
| 120 | 37.31 | 2.99 | 1.93 |  | 60 |
| 140 | 37.56 | 2.72 | 2.15 |  | 70 |
| 160 | 40.95 | 3.09 | 2.26 |  | 80 |
| 180 | 43.32 | 3.56 | 2.18 |  | 75 |
| 200 | 45.39 | 3.68 | 2.30 |  | 75 |
| 220 | 48.37 | 2.38 | 3.97 |  | 80 |
| 240 | 43.79 | 2.11 | 3.76 |  | 80 |
| 260 | 34.23 | 2.70 | 1.76 |  | 75 |
| 280 | 34.61 | 2.24 | 2.18 |  | 65 |
| 300 | 35.52 | 2.57 | 2.01 |  | 65 |
| 320 | 36.76 | 3.07 | 1.82 |  | 65 |
| 340 | 36.63 | 2.67 | 2.08 |  | 65 |

a. The presence of oxide and other forms of contamination may not be able to be removed and may impede diffusion between the bonding metals. This may lead to unsuccessful bonding or lower bonding strength with poor IMC.

b. The application of appropriate and adequate temperature will soften the metal surface and accelerate the diffusion between the bonding systems.

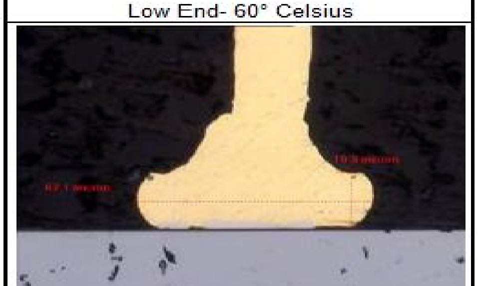
c. Higher application of temperature may cause the atom to diffuse to each other more quickly and may cause cracks and voids in the interface; Results of this experiment show voids at higher temperature range in Table 2, leading to lower bonding strength.

**II. Effect of Temperature on Ball Bond Deformation**

Results of this experiment shows significant difference in ball bond profiles with respect to different temperature levels. Research carried out previously with the application of short-time Fourier transform (STFT) to input/ output power of an ultrasonic transducer is able to deduce this phenomena [11, 12].

The ball bond image in figure 3 shows a thicker ball deformation as compared to at higher temperatures. At 60°C the gold ball bond thickness obtained is 19.9um. The available theory [4] depicts, at this stage of lower temperature, the impedance of piezo-transducer is low and the consumed power of piezo-transducer is high. This may result in poor exertion of bonding power to the ball bond. This result co-relates to the lower ball shear strength and lower IMC that was obtained in this study

Low End- 60° Celsius

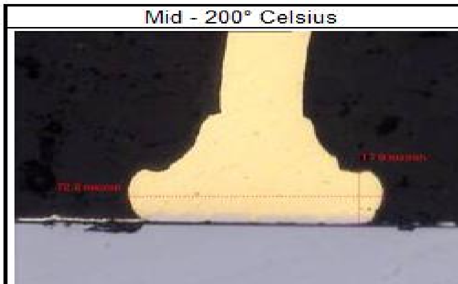


| | |
|---|---|
| Ball Thickness(um) | 19.9 |
| Ball Diameter (um) | 67.1 |

Fig 3: Ball Bond profile at 60°C

Results of experiment at temperature range 200°C to 220 °C shows; this is a good range which results in the desired output response. The impedance of piezo-transducer is high and the consumed power of piezo-transducer is low. This effect may exert adequate physical bonding power to the bonded aluminum interface and result in a thinner ball bond of 17.9um; Figure 4. Intermetallic coverage response from the experiment carried out in this temperature range is observed to be much uniformed and homogeneous as compared to the lower range temperature.

Mid - 200° Celsius

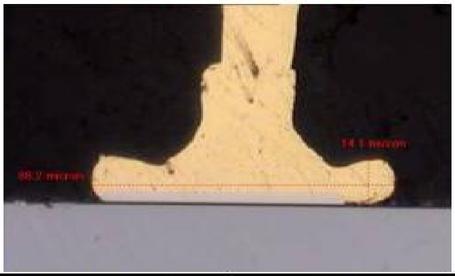


| | |
|---|---|
| Ball Thickness(um) | 17.9 |
| Ball Diameter (um) | 72.8 |

Fig 4: Ball Bond profile at 200°C

Results of ball bond obtained at higher temperature shows a thinner ball bond of 12.5um; Figure 5. At this state, the available theory from previous study depicts, impedance of piezo-transducer is higher and the consumed power of the piezo-transducer is lower. This effect may result in higher physical exertion of bonding power to the ball bond and produces a thinner ball bond of 12.5um. This result co-relates to the low shear strength obtained from this study, and may attribute to the non-uniform and non-homogenous intermetallic coverage which shows voids in the center of ball bond.

High End- - 320° Celsius



| | |
|---|---|
| Ball Thickness(um) | 12.5 |
| Ball Diameter (um) | 86.2 |

Fig 5: Ball bond profile at 320°C

## 4. Conclusion

From the experimental measurements, the effect of applied temperature on deformation of gold ball bond in Au-Al thermosonic wire bonding was investigated. It is revealed and understood that poor gold bonding happens with low temperature which produces thicker ball bonds which results in lower bonding strength and poor intermetallic coverage. The application of high temperatures lead to ultra thin ball bonds and also results in lower bonding strengths and poor intermetallic coverage. Only when moderate temperature is applied, good shear strengths are attained with homogeneous intermetallic coverage from the medium ball bond thicknesses obtained

It is concluded that, applied bonding temperature, unaccompanied by other bonding factors, has an effect on ball bond deformation, bonding strength and intermetallic coverage. Further studies and experimentation of pre-heating on bonding surfaces should be explored for enhanced wire bondability

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