Effect of mechanical properties of gold wire on looping behavior and pull strength for QFN Stacked Die Package

A. JALAR1, 2, S. A. RADZI1, S. ABDULLAH2, M. F. M. YUNOH2 AND M. F. ROSLE1,
1School of Applied Physics, Faculty of Science and Technology
2Institute of Microengineering & Nanoelectronics
Universiti Kebangsaan Malaysia,
43600 UKM Bangi,
Selangor, MALAYSIA
azmn@ukm.my

Abstract: Gold is commonly used in the field of electronic manufacturing as bonding wire that connects the IC chip and circuit board. The effect of trace elements on the mechanical properties of 4N gold wire has not been widely investigated for some years despite the important of wire-bonding and the move towards fine pitch applications. The objective of this study is to determine the effect of mechanical properties of two type of gold wire (wire A and wire B) on looping and pull strengths. Both wires with diameter of 25.4 μm were bonded using K&S Maxum by maintaining the temperature at 200 ºC. Due to the element analysis, atomic percentage of Ca in wire B is higher than wire A. Pull strength increase with the increasing of the trace element. The higher pull strength of wire B could improve the yield strength, elastic modulus and recrystallization temperature.

Keyword: Wire bonding, Ultrasonic (USG) current, QFN packaging, ball bonding

1 Introduction

The trend in semiconductor industry is moving towards miniaturized footprint, cost reduction and multifunctional components with higher inputs and outputs. 3D Quad Flat No-lead (QFN) stacked die has become the package of choice due to its good thermal performance, flexibility in matching any leaded footprint, fast turn-around time and low tooling up cost. 3D packaging offers attractive way to reduce transmission delays, since its configuration provides much shorter access to several surrounding chips [1]. Stacked die typically categorized into two basic configurations which are pyramid and tower stacked die. For this study, pyramid configuration was used by stacking a smaller die (top die) on the top of the bottom die using die attach film (DAF). Samples were prepared using test die (Daisy-chain) with the overall package dimensions was 7 x 7 x 0.9 mm³, QFN 48 leads package as shown in Figure 1.

To accommodate this trend, desired loop shape, low looping capabilities and high wire bond strength were required for stacked wire bonding profile. In low loops, reduction of neck area due to plastic deformation as the wire is bent may affect the current capability, lead to additional stress and may accelerate fatigue effects during power and temperature cycle [2]. It is important to fully understand the dynamic characteristics of the wire mechanically and looping process to develop better design tools to quickly obtain an optimum stacked wire bonding profile.

Looping may become more complicated as the upper die was reduced in size and wire loops increased in length. Therefore details consideration on the mechanical properties of the suitable wire type is required to ensure optimum quality and reliability performance. The effect of material properties to the bonded and unbonded gold wire reliability has been described in details by various studies [3-7]. Beside that looping performance also be attributable to the amount of alloying dopants in as-drawn gold wire. Lichtenbrger et al. [8] studied the effects of Be, Cu, Ag, Ca, Pt and Al additions to pure gold in conjunction with a hydrostatic wire-extrusion process. Ohno et al. [9] investigated higher dopant levels generally give higher strength, higher elastic modulus, and higher recrystallization temperature.

This study main worked was performed to investigate the effect of Ca trace element level in the as-drawn gold wire towards the mechanical strength of the heat affected neck region and looping behavior. Therefore, universal testing machine 5564 had been used to observe the effect of Ca trace element level to the yield strength, ultimate tensile
strength and the elongation break of as-drawn gold wire. While pull test performed by XYZ TEC Condor testing machine was used to compare those mechanical behavior to the low loop bonded gold wire. Results from this study will provide a mechanical understanding on gold wire behavior contained different Ca trace element level and helps in the selection of wire type for robust and high reliability performance of gold wirebonding.

2 Materials and Methods

2.1 Tensile test for gold wire
In order to understand the mechanical properties of both wire A and B such as tensile stress, strain and elastic modulus, tensile test using Instron Micro-Universal Testing Machine 5564 was performed according to the American Society for Testing and Materials (ASTM) standard. The length of the wire used for the tensile tests was 80 mm, and the load rate was 1.0 mm/sec.

2.2 Package Assembly
Samples of 3D stacked die package was prepared using daisy chain die with the overall package dimensions was 7 x 7 x 0.85 mm³, QFN 48 leads package. The bottom die size was 5 x 5 mm² and the top die size was 3.3 x 3.3 mm², where thickness for both dies is 0.15 mm. Upon completion of die attach, the die-attached samples were bonded using K&S Maxum Elite wire bonder by maintaining the bonding temperature at 200°C. A commercially available 25.4 µm (1mil) gold wire diameter was bonded on 55 µm Al bond-pad-pitch. Optimized bonding parameters were used during bonding process which includes bonding force, ultrasonic current, bonding time, temperature and scrub mode. The optimized parameters of wire bonding requirement process are showed in Table 1.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Ultrasonic Current (mA)</th>
<th>Bonding Force (gf)</th>
<th>Bonding Temperature (°C)</th>
<th>Bonding Time (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultrasonic Current (mA)</td>
<td>70</td>
<td>30</td>
<td>200</td>
<td>15</td>
</tr>
</tbody>
</table>

The shear and pull test is the most universally accepted method for controlling the quality of the wire bonding operation. Fig. 2 shows the schematic of ball pull test which a small hook is attached to the centre of wire looping. Ball size and ball thickness were measured using XYZ TEC Condor tester to get the consistent of wire bonding performance.

3 Results and discussions

3.1 Effect of alloy elements on mechanical properties
One of the most important aspects to select a suitable wire type to be used for a low loop application is to establish the relationship between the wire compositions and mechanical properties dependent on the elongation and tensile strength. Elemental analysis by EDX detected different amounts of Ca and Mg doping element in both type of gold wire A and B as shown in Table 2. Ca is an effective hardener above 10ppm and has an immediate benefit to a short HAZ by increasing the recrystallization temperature. Higher element trace of Ca gives higher strength, higher elastic modulus, and higher recrystallization temperature. Higher recrystallization temperature would result in shorter heat affected zone (HAZ) length and thus, form
lower loop height.

Table 2 Atomic percentage for wire A and B

<table>
<thead>
<tr>
<th>Element</th>
<th>Atomic percentage (%) Wire A</th>
<th>Wire B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mg</td>
<td>1.1</td>
<td>0.12</td>
</tr>
<tr>
<td>Ca</td>
<td>1.21</td>
<td>3.62</td>
</tr>
<tr>
<td>Au</td>
<td>97.68</td>
<td>96.26</td>
</tr>
</tbody>
</table>

Elastic behaviour of both gold wire A and B are represents by the stress-strain curve as shown in Fig. 3(a) and (b).

As present by the stress-strain curve, B demonstrate extended plastic deformation compared to wire A. The testing results indicated that the tensile strength of wire A was about 174.02 Mpa while wire B showed 285.4 MPa which is 111.38 MPa higher of acting force applied on the wire unit area. Therefore the changed in dimensions per unit length or elongation of the wires also present a significant improvement from 0.50% for wire A to 1.64% for wire B as the Ca doping amount increased. It was concluded that higher of Ca doping amount was seem to affect the improvement in the gold wire mechanical strength.

Chew et al. [10] reported that increasing amounts of Ca raised the yield strength, ultimate tensile strength and the elongation break. According to Wulff and Breach [11], a strengthening mechanism may be due to the microsegregation of specific dopants along grain boundaries, especially larger atoms like Ca. The atomic size of calcium is 30% larger than gold, and so it would be expelled from the lattice and find it’s place at grain boundaries. The hardening effect of grain boundary constituents (Ca) is not as quickly apparent, but their grain boundary presence pins these zones and eventually increases strength but more importantly increases the recrystallization temperature.

3.2 Effect of element traces to wire looping behaviour

Looping profile for stacked wire bonding built in this package requires a combination of high and low looping to prevent wires from touching one another. To ensure no expose wire the wire bonding for top die was control to have lower looping as compare to the bottom die. Therefore only the wire bonding for top die were optimized and been given critical attention.

Fig. 4. Stacked wire bonding configuration developed in this study.

High speed and stacking configuration of wirebonding required stronger wire especially with higher breaking loads and elongations. During wirebonding process, the wires were rapidly pulled through the bonding capillary and force to bent, therefore these distinctive features was necessary to strengthen the head-affected neck region and give high yield strength to the bonded wires. Besides that, specific wire stiffness is also required to maintain long lengths without undo deflection in the horizontal which called sweep and vertical planes as sagging.
Wire sweep usually happen at the gate and air vent during molding process, so in this case the observations are focus at the both area as shown in Fig. 5.

According to wire sweep images, large deflection had been observed through wire A compared to good formation of wire B where the calculated value of wire sweep percentage for both wire A and B were 8.019% and 1.873% respectively.

Fig. 7 Wire type B has higher wire pull values

Fig. 7 presents the pull test results for wire A and B. Results determined that wire B had higher stiffness against lateral forces during wire pull test compared to wire A. The average break strength for wire B was found to be 11.84gf with a standard deviation of 0.502gf. While, the average break strength for wire A was found to be 11.68gf with a standard deviation of 0.707gf. As showed by tensile test results, similar trend was observed for wire pull test results where pull or yield strength of the bonded wires increased with the increasing of Ca dopants amount. Liu et al. [12] derives that the amount of Ca dopant has great effect on the strength of the gold wire.

Saraswati et al. [13] suggested that this could be partially caused by the grain refining effect and recrystallization inhibitor of Ca dopant during the manufacturing process of the gold wire. Various study found that finer grain size in the HAZ region cause the wire yield strength to be increased. This meet a good agreement with the experimental data done in this worked and can be explained by Hall Petch equation.

$$\sigma_y = \sigma_0 + k d^{1/2}$$

Where $\sigma_0$ is the lattice resistance (friction stresses which opposes the dislocation motion), $k$ is the dislocation locking term constant and $d$ is the grain size. The experimental data done by Yahya et al. [14] validated the Hall Petch equation and proved that the low loop bending within the HAZ length must be controlled further away from the larger grains area to achieve high reliability performance.

The bond strength of two type wire is measures for the ball bond quality. Fig. 5 showed the box plot of ball shear values evaluating the quality of ball bonding. The shear strength of wire B is higher than wire A. The median of shear strength for wire A is 36.5gf while wire B is 43.7gf. The interquartile range for wire A and B are 35.42 to 38.55gf and 42.58gf to 46.45gf. However, an abnormally wide pipe was created for both wires. From Table 3, the averages of ball size of wire B is higher than wire A.
4 Conclusion

The mechanical properties of the gold wire were characterized prior to wire bonding process. Tensile test present that wire B has higher tensile strength with 285.4 Mpa compared to wire A which is 174.02 MPa. Higher percentage of Ca, as an element detected by EDX analysis in wire B conclude that it gives higher strength, higher elastic modulus, and higher recrystallization temperature. Increases in element trace necessitate increase in an elongation of the wire and allow proper low loop and prevent wire sweep in ball bonding for stacked die package. The structure of the gold wire can be proved with the microstructural analysis, which is a part of our future works.

References:


