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# LOW LOOPING CHALLENGES IN THE QFN WIRE BONDING PROCESS

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## ABSTRACT

Low looping in bonding wire is become more challenges in the current technology application of advanced packages. In an advanced application, the wire bond process is demanded 100μm low loop height for three dimensional stacked die packages. The purpose of applying the low loop wire bonding is to form the minimum overall package size. The growth of stacked die packages and its requirement for a low profile gives so many challenges the wire bonding process. This paper examines the capability of the low looping advancements in today's wire bonder to meet the unique challenges associated with stacked die applications. It determines the factors that should be considered in the forming of the low looping using soft gold wire. The lowest achievable loop heights are physically constrained by the dimensions and plastics deformation behavior of the wire. The type of loop that has been used in this study is worked loop because it takes a short duration per bond and also the fastest. The demand for stacked die, die-to-die and multi-tiered packages have produced a demand for low loop in wire bonding process.

## INTRODUCTION

Wire bonding is one of the most important process steps in semiconductor devices packaging. It provides the ultimate means for interconnections between the inner and outer "world" of any semiconductor device [1]. Driven by continuous demand for smaller, lighter, faster, cheaper, more advanced and more feature-rich portable and hand-held electronics, lower, longer, flatter or more in-board wire bond are critical for the majority of the world's advanced IC packages such as stacked die and multi-tier devices.

In stacked die packages, high and long loops are required in addition to the low loops. Both high and low looping capabilities of gold bonding wire are important, but the ability to form low loops in thinner packages is a key property for bonding wires in thin and ultra-thin packages. Unlike high looping form, low loops often plastically deformed the wire at the neck [2]. Thus, it gave a low looping is one of the most important requirements for the advanced packages, particularly for stacked dies [3]. There are several specific reasons why the wire bond loops need to be lowered in today's advanced packages such as:

- prevention of capillary damage to the wire in fine-pitch devices,
- reduced looping space due to thin dies and interposers in same-size stacked die applications

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- prevention of lower-tier wire-wire shorts in multi-tier wire bonds
- prevention of wire-die short in in-board and stacked dies
- general prevention of wire sweep and avoidance of wire exposure at molding due to thinner packaging [4].

The broken neck is the common failure in wire bonding process. The neck of a bonded wire is the connection between the wire profile and the bonded ball. The capability of the wire to bent lower is according to the grain at the neck.

Mold sweep also gives the big effect for the stability of the wire looping. Low viscosity compound with smaller filler size and slower molding transfer speed shows the improvement in sweeping of the wires [5]. Lower wire loop height leads the greater mold sweep stiffness and this situation simulated by mold sweep experiment. It happened because if the looping is higher it will give the low stability in mold sweep [6]. Therefore, the low wire looping provides an advantage during the encapsulation process.

## BACKGROUND OF WIRE LOOPING FAILURE

Typically, wire loops on a bonded package suffer random height variations or defects, in various levels of frequency and severity, depending upon the process complexity and the manufacturing capabilities [7]. 2% to 3% yield lost can be resulted from shorts in stacked-die applications. Typical types of looping failures include:

- S'ing - the undesired "S" shape of a wire loop occurring in several types of looping failures, such as:
  - Wire kink - A mechanical kink anywhere along the wire loop severe enough to cause adjacent wires to contact each other
  - Wire sagging - Commonly found on wires bonded to the power/ground signal bar of BGA devices, where the wire tends to sink due to its own mass. This defect also may be a result of inconsistent wire payout
  - Wire sway - Commonly observed on wires exiting from the corner of a bonded package
  - Wire sweep - Commonly observed on relatively long wires, particularly after molding encapsulation process
- Wire leaning - describes cases when the wire is not vertical to the ball bond at the initial part of the wire loop. This can easily cause adjacent wires to come in contact with each other, as this is where the distance between loops is the smallest along the wire
- Wire contact - when one wire is in actual contact with any other wire. This may occur with any neighboring wire (adjacent, beneath, or above), such as in multi-tier or stacked-die package types
- Wire scratch - the wire is damaged because of mechanical friction with any of the parts along the wire path (diverters, tubes, wire clamps, capillary) [7].

Corresponding Author: shahrum@eng.ukm.my

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The QFN stacked die packages need a complicated wire bonding process. Many factors have to be considered to get the best looping. Figure 1 shows the two levels of stacked die and the type of looping for the package.

Figure 1: Wire bonding on two levels of stacked die [7].

## MATERIALS AND METHODOLOGY

Gold bonding wire is normally specified as 99.99% (4-9's) purity, while chemistry the residual 100ppm is carefully controlled to provide the required mechanical and electrical properties. When the ball is formed by proper ball forming condition wire is inevitably affected by heat because the ball part fully melting during ball forming so the boundary which is affected and non-affected range is occurred and it is called heat affected zone (HAZ) as shown in Figure 2.

The grain size at the ball neck grows by the heat of about the melting point and the grain size becomes smaller along the wire length as the affect of heat decreases [8]. The mechanical properties of the HAZ will always be lowest strength, stiffness and higher ductility. During the looping process, much of the bending will naturally occur within the HAZ. Wire chemistry can play an important role in providing a short HAZ, with high strength and ductility. A short HAZ will provide lower, more repeatable loops [9]. The ability of the wire to bent lower is according to its HAZ.

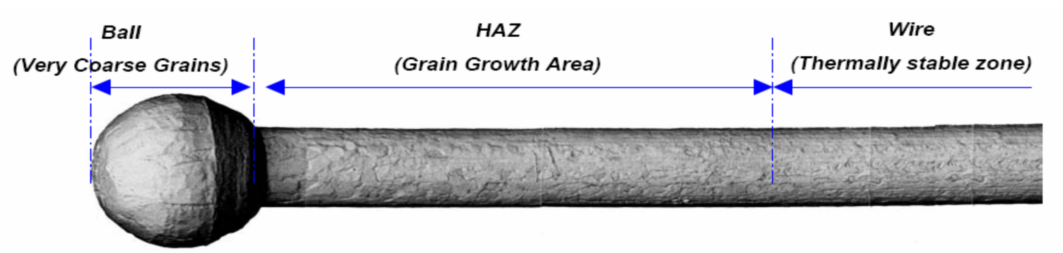


Figure 2: Heat Affected Zone [8].

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This experiment used soft wire that has been applied in very low loop application. The mechanical properties for 25.4 µm wire are tabulated in Table 1:

Table 1: Mechanical properties for the wire [10].

| Mechanical properties | Value |
|---|---|
| Breaking load (gf.) | 10.0 ~ 16.0 |
| Breaking load (mN) | 98.0 ~ 157.0 |
| Elongation (%) | 2.0 ~ 7.0 |

Many variables such as the air pressure for the wire feed assembly of the wire bonder (wire tensioner), EFO parameter, capillary dimension and gold wire character are affected from wire neck strength. However, this study focuses on the looping trajectory that induced mechanical stress on the neck of the wire ball bond. This work also included the observation of the wire formation to bend and give 0.1016mm (4mils) of loop height.

For this experiment, the wires were bonded on the bottom die to lead (Group 1) and top die to lead (Group 2). These two groups are consist different looping parameter but they are in the same looping type. The type of loop that was applied in this process is worked loop. Worked loop means ball bond was formed at the first bond and go to lead with wedge bond and there is a value for flat length. Looping parameter values that have been used to get the low loop height are shown below (Table 2).Schematic diagram of wire configuration accordingly to Group 1 and 2 can be referred in Figure 3.

After the wire bonding and molding process, the units were randomly selected in order to check the failures that have encountered the packages. The observation was performed using microscope after decapsulation.

Table 2: Looping parameter.

| Parameter | Group 1 | Group 2 |
|---|---|---|
| Kink height (mils) | 4 | 4 |
| Reverse motion (mils) | 4 | 4 |
| Loop factor (mils) | -4 | -4 |
| Flat length (mils) | 15 | 48 |
| Shape factor | 28° | 28° |

**1 mil = 0.0254 mm*

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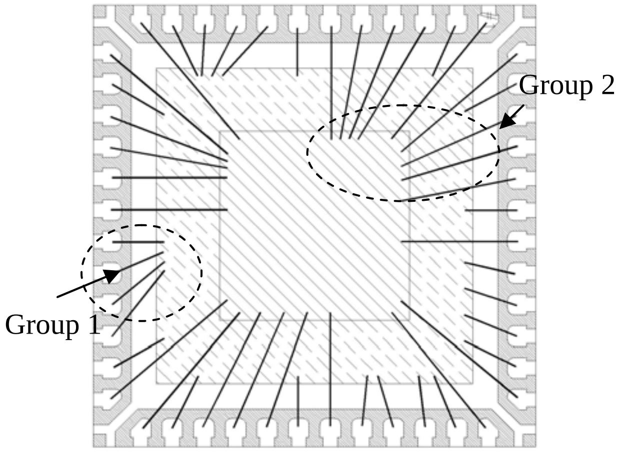


Figure 3: Schematic diagram for the bonded unit.

## RESULTS AND DISCUSSION

The experimental results show after the molding process that there were some failures on wire looping formation at the packages. Two rejected units have been randomly selected and compared to the good units using TOSMICRON-S4090IN Series. The X-ray has the capability to get the high contrast that can obtain X line drawing image with high sensitivity and high accuracy table adoption and inspection speed efficiency. The maximum enlargement ratio approximately 205 times and five milimicron nominal focuses. It can turn 360° using the slewing mechanism in observation of object inspection [11].

Figure 4 shows the image of good unit from top view and side view using X-ray. There was no failure such wire sweep, wire sagging or wire exposed were observed. However, this is just the external view. This device cannot observe the necking problem but we can see there is some wires tight condition on the top die that will cause the necking.

There are some rejected units are observed because of the stability of the soft wire. After molding process, the possibility of problems because of the sweeping of the mold compound are very high to occur the packages. The soft wire has low strength, therefore it will caused the wire sweeping problems such as wire sagging, sway or wire contact. Figure 5 shows the reject unit because of wire short or contact. Figure 5(a) shows the image taken by X-ray that obviously shows that there was a wire short problem. After decapsulation, the unit was observed by high power scope to close up the image of the problem area. The wire short maybe because of the mold sweep. The mold compound flow to one panel of the strip, so that the sweeping of the wire for each unit is different. It can be said that the wire short because of the velocity of the mold flow is high at the area of the unit.

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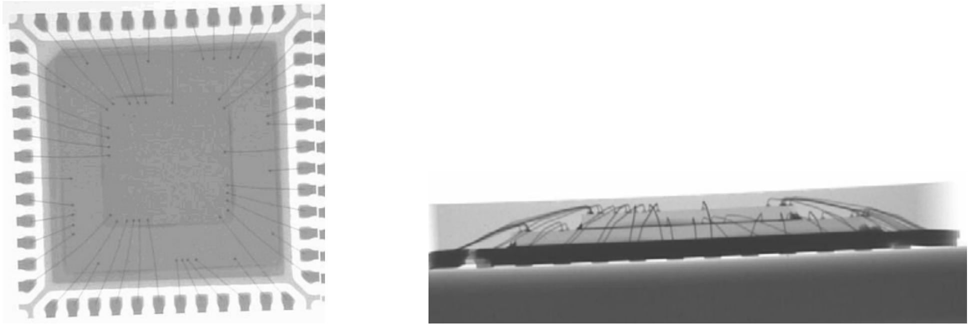
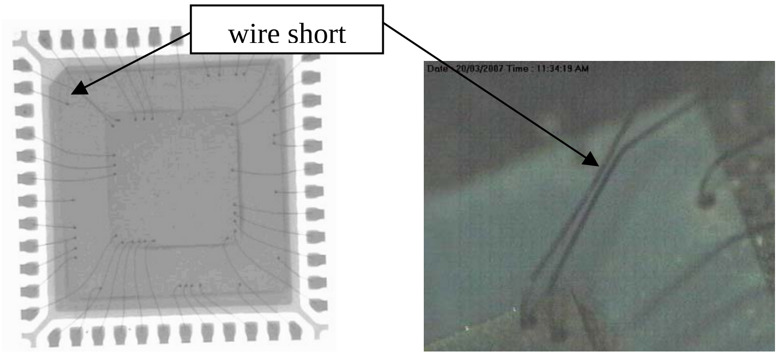


(a) (b)

Figure 4: The image of good unit taken by X-ray TOSMICRON-S4090IN Series: (a) top view, (b) side view.

There are some common failures such as wire non-stick on lead, non stick on pad (Figure 7) and broken wedge occurred the packages. These problems were caused by parameter settings and handling by the operator.




(a) (b)

Figure 5: Failure that might be caused by wire short: (a) actual image, (b) enlarge image.

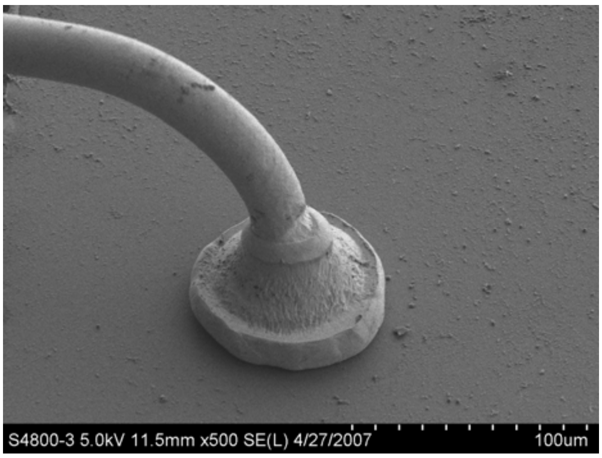



Figure 6: Occurrence of neck of gold wire observed using SEM.

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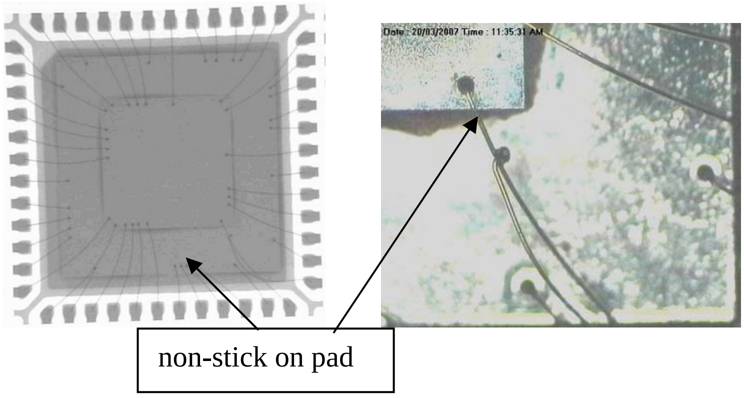


(a) (b)

Figure 7: Failure caused by non-stick on lead: (a) actual image (b) enlarge image

Finally, this experiment used dummy die sputtered by aluminum layer, which caused the mirror die and it was hard to the pattern recognition system (PRS) of the wire bonding machine to detect the bond area. Using actual die for the future experiment is the best recommendation to get the better results.

## CONCLUSION

The capability in low looping needs the consideration of many factors such as the looping parameter, mold sweep and the selection of the capillary. The usage of the soft wire must be suitable with the mold compound because in molding process the filler can sweep the wire that can cause broken wire or necking. The lower loop height needs the smaller filler size to get the stable wire formation. For the conclusion, the flexibility of the wire bonding enables the successful use of the new packaging technologies such as stacked die and multi-tier packages.

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