OPTIMIZATION OF STACKED DIE QUAD FLAT NO LEAD (QFN) PACKAGE RELIABILITY THROUGH DESIGN AND VIRTUAL PROTOTYPING

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ABSTRACT

Stacked die IC (integrated circuit) package configuration has now gained popularity as a solution to the need for thinner, smaller and cost effective package with increased functionality. This usually involves the use of thinner stacked dice and die attach film. But with die attach film material, delamination is a problem that has to be overcome. Interface adhesion must be strong enough to resist the tendency of the package interface to delaminate under MSL (Moisture Sensitivity Level) testing and thermal cycling.

This paper presents the optimization approach used in the development of a thin Quad Flat No-lead (QFN) stacked die package. Delamination between the two bottom dice and the leadframe was the main problem encountered during the initial phase of the thin QFN stacked die package development. To solve the problem and produce a robust thin QFN stacked die package, design and virtual prototyping or modeling were utilized. Different types of lead frame designs were considered to come up with an optimum package that would pass reliability requirements especially MSL 3 (i.e. no interface delamination after moisture soak and 3x reflow cycles).

1.0 INTRODUCTION

With the current semiconductor industry trend on package miniaturization and the need to add more functionality, QFN (Quad Flat No-lead) package with stacked dice has become a good choice for a low cost package alternative to substrate or laminate package. And since there is very limited space, with additional complication of a thin die, using die attach glue is not anymore feasible. Die attach film (DAF) has become the die adhesive commonly used for thin stacked die packages. Though DAF has advantages over glue, there are still manufacturing concerns like DAF voids and delamination.

In this study, the delamination problem encountered during the development of a new QFN stacked die package and the optimization approach used to come up with the robust design would be presented. Figure 1 shows the schematic of the stacked die package configuration considered. The package has three dice: Die 1 and Die 2 at the bottom, which are bonded to the lead frame using DAF and the other die (Die 3) is mounted on top of the 2 dice. The development of the said QFN stacked die package has become very challenging due to the fact that the three dice must fit in a thin package (0.55mm total package height) and this can only be done by thinning the die to around 105µm and using DAF instead of the standard die attach glue material.

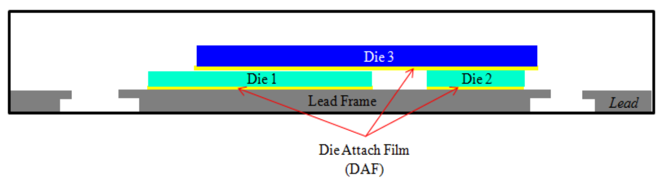

Figure 1. Schematic of the QFN stacked die package.

2.0 REVIEW OF RELATED LITERATURE

2.1 Package Die Stacking

There are typically two common methods for die stacking [1] i.e., epoxy die bonding, and thermoplastic tape bonding or film adhesive. The application of epoxy for die stacking is well established for standard die bonding onto the lead frame and substrate, but epoxy bleed out can be an issue. Non-sticking of bonded wires could be caused by epoxy bleed material flows to the bond pads. The second method uses thermoplastic tape bonding for uniform and stable bond line thickness (BLT) control with uniform fillet.

The die attach film (DAF) in the second method replaces paste in stacked packages for its good control of paste bleed, creeping effect to die edge in addition to consistent bond line thickness (BLT). Die attach process for DAF is very much different from that of epoxy glue or paste. Optimization is unavoidable to ensure process robustness and package reliability when DAF is used. The major process difference as compared to conventional die attach process is the heat bonding. The most important process consideration is the repeated heat cure during die attach which may affect the material property. If the DAF is cured before molding process, chances of delaimnation between die and DAF interface is high.[2]

2.2 Lead Frame Interface Delamination

Interface delamination at Moisture Sensitivity Level (MSL) test has been a constant headache in the semiconductor . For lead-frame based package, a similar study[3] was conducted on TSOP (thin small outline package). It was found out that mechanical roughening is not a good method to eliminate delamination at MSL even though the cost is cheaper. Adding dimple to some controlled depth, grinding to a certain roughness and EDM with blasting were the mechanical roughening techniques evaluated but failed. Copper lead frame roughening using brown oxide was also tested but there were still units with delamination. And using higher adhesion molding compound was proven to reduce the delamination but not sufficient to eliminate the delamination. However, a preplated lead frame (PPF) with some upgraded roughening has been able to provide delamination solution to TSOP product. There were no details however about the said upgraded roughening and it was only tested on TSOP and addressed the issue of mold-leadframe interface delamination and not on DAF to leadframe delamination as encountered in QFN stacked die package.

3.0 EXPERIMENTAL SECTION

3.1 Package Modeling and Simulation

The QFN stacked die package was being modeled to assess warpage and stress levels. The package is having a size of 6x6mm with 0.55mm thickness. Figure 2 shows the 3-D finite element (FE) model. Due to half package symmetry, only half of the package was modeled to minimize computer simulation time and the number of elements. This model was also used to study different sets of package materials.

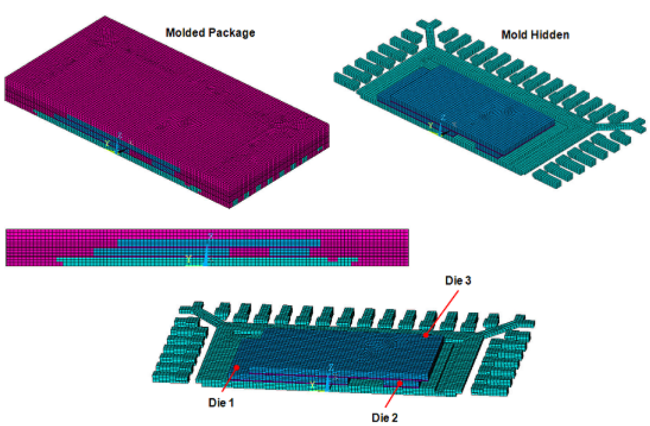

Figure 2. Finite element 3-D model of the QFN stacked die package.

Then a 2-D model (Figure 3) was also used. Then different package configurations that would possibly result in lower interface stress levels were analyzed (Figure 4).

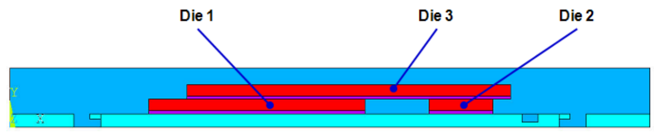

Figure 3. 2-D model of the QFN stacked die package (original design – baseline model).

Figure 4. 2-D model of the different package configurations.

3.2 Actual Evaluation of Lead Frame Designs

Since there were some limitations on time and resources, the actual evaluation just focused first on two lead frame designs and three DAF materials. Design #1 was the standard preplated lead frame and design #2 was having roughened Ni lead frame surface. But there was also one evaluation run in which the lead frame was roughened by laser engraving. Table 1 gives the details of the evaluation matrix.

Table 1. Lead Frame Design Evaluation Matrix

Leg #	Lead Frame Design	DAF Material
1	**Design 1:** Standard PPF Lead Frame	DAF 1
2	**Design 1:** Standard PPF Lead Frame	DAF 2
3	**Design 1:** Standard PPF Lead Frame	DAF 3
4	**Design 2:** Roughened Ni	DAF 1
5	**Design 2:** Roughened Ni	DAF 2
6	**Design 1:** Roughened Ni	DAF 3
7	Design 1 but roughened by laser engraving	DAF 1

4.0 RESULTS AND DISCUSSION

Package mechanical modeling shows that warpage is in "frowning" mode at room temperature (Figure 5) and this agrees with actual package warpage mode observed. And Figure 6 displays the interface stress contour indicating high stress areas where actual delamination initiation was also observed.

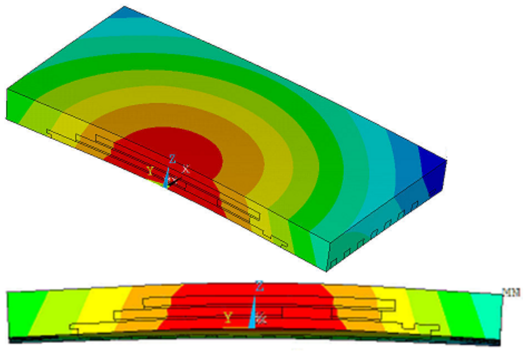

Figure 5. QFN stacked die package warpage result at room temperature ("frowning" mode).

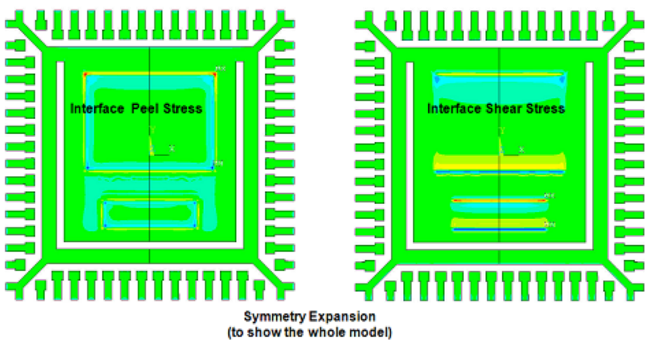

Figure 6. Lead frame interface (peel) stress result at MSL reflow showing high stress areas at the location of bottom die edges.

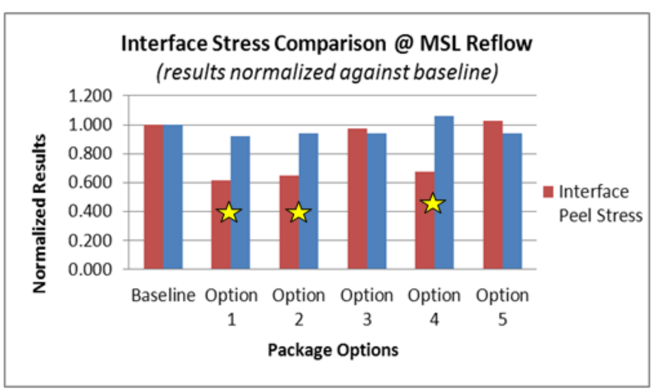

Figure 7. Interface stress results for the different package configurations.

From actual evaluation results, the standard preplated lead frame design still resulted in delamination even when used with different die attach films (DAF 2 & DAF 3). Total delamination (Figure 8) was seen after MSL 3 testing. And Figure 9 cross-section photo shows confirmation of the delamination.

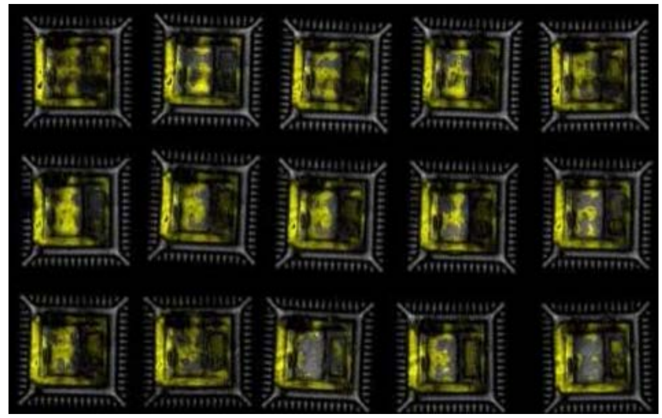

Figure 8. Scanning Acoustic Microscope (SAM) photo showing total delamination with the standard PPF.

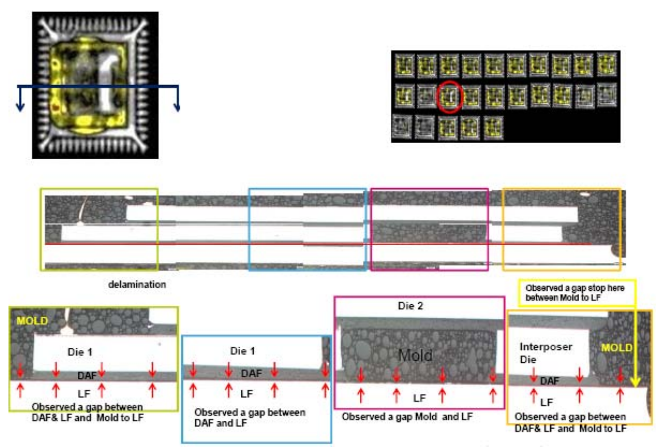

Figure 9. Cross-section photo confirming the delamination encountered.

The lead frame roughened by laser engraving also resulted in total delamination (Figure 10). It could be that oxidation also contributed to the problem because laser engraving would remove the plating of the lead frame Cu base.

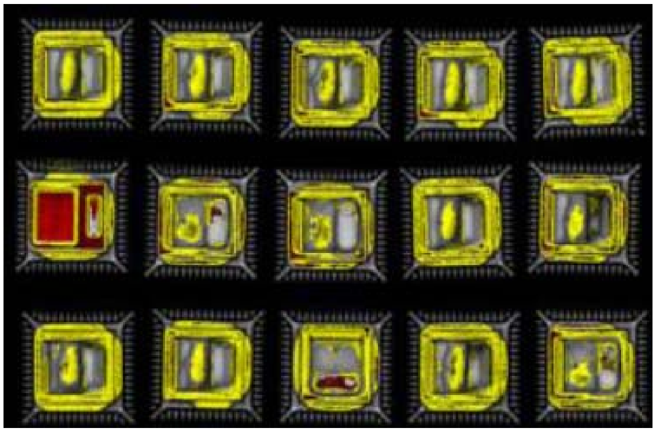

Figure 10. Scanning Acoustic Microscope (SAM) photo showing total delamination with PPF roughened by laser engraving.

However, the roughened Ni lead frame provided a very promising result in terms of delamination. It indicated that the roughened had significantly improved the lead frame interface adhesion. Figure 11 showed the SAM photo of the better performing roughened Ni lead frame.

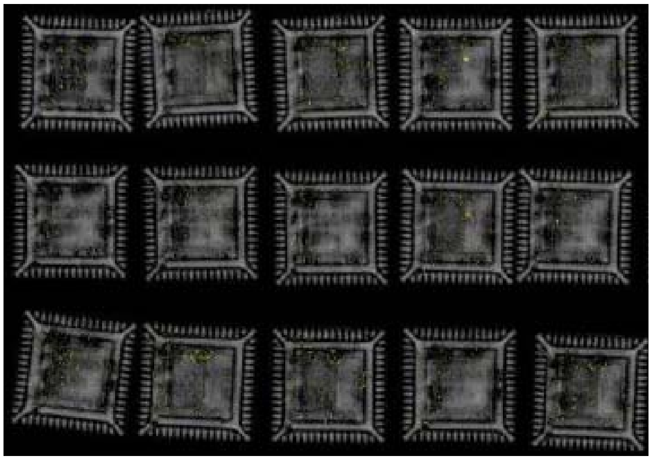

Figure 11. Scanning Acoustic Microscope (SAM) photo showing no delamination with roughened Ni.

The evaluation results are summarized in Table 2. It has been demonstrated that roughened Ni is an effective method of increasing interface adhesion and eliminating delamination at MSL.

Table 2. Summary of Evaluation Results

Leg #	Results	Remarks
1	Failed	With delamination
2	Failed	With delamination
3	Failed	With delamination
4	Passed	No delamination; survived thermal cycling after MSL
5	Passed	No delamination; survived thermal cycling after MSL
6	Passed	No delamination; survived thermal cycling after MSL
7	Failed	With delamination

5.0 CONCLUSION

Based on the results, it is concluded that developing a thin QFN stacked die package could be successfully achieved by optimization through design and virtual prototyping.

For the design optimization, this study showed that one most effective way of eliminating delamination is by increasing lead frame interface adhesion. This could be best achieved by using roughened Ni lead frame design, which provides optimum interlocking between DAF and the leadframe surface.

6.0 RECOMMENDATIONS

For a thin QFN stacked die involving thin dice and die attach film (DAF), it is recommended that roughened Ni lead frame design be used to produce a delamination-free package. This is the design solution that is proven to work in situations having a challenging stacked die configuration that would not work without delamination if standard PPF lead frame design is used.

7.0 ACKNOWLEDGMENT

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8.0 REFERENCES

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9.0 ABOUT THE AUTHORS

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