THE EFFECT OF GLUE BOND LINE THICKNESS (BLT) AND FILLET HEIGHT ON INTERFACE DELAMINATION

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ABSTRACT

The use of epoxy glue die attach material to bond silicon die onto a substrate or lead frame in an IC (integrated circuit) package is still very popular. But there are different challenges associated with using glue die attach like the need to control bond line thickness (BLT), fillet height, voiding and bleed out. Reliability issues like delamination could happen when there is problem with the die attach material in the package assembly.

In this study, the effect of glue bond line thickness and fillet height on interface delamination in a Quad Flat No-lead (QFN) package was investigated using mechanical modeling and experimental evaluation. Based on the results, it was found out that increasing fillet height beyond an optimum value would not help create a robust IC package but instead increase the risk of delamination. This paper would also show that modeling or virtual prototyping could help understand delamination, find optimum BLT and fillet height as well as locate high stress areas that correlate with actual package or die attach failure signature.

1.0 INTRODUCTION

Quad Flat No-lead (QFN) package is widely used in the global semiconductor industries because it has many advantages including reduced lead inductance, can be smaller near to chip scale footprint, thin profile and low weight. It has perimeter I/O pads to ease PCB trace routing and has an exposed die paddle technology that offers an efficient heat transfer path out of the IC directly to the PCB and enables stable ground by the use of down bonds or electrical connection through a conductive die attach adhesive.[1] Most common basic material components of a QFN are Integrated Circuit (IC) commonly made up of silicon material, lead-frame usually having a copper core material, wire usually gold or copper, mold compound resin and the die attach adhesive either in epoxy glue or in film as illustrated in Figure 1.

Generally, this package is already considered mature in the semiconductor industry and has 0-hr stable process performance. But during the development of a QFN package with a body size of 5x5mm and a die size of 2x2mm,aggravation of die attach delamination during thermal cycling was encountered in spite of the fact that the package materials especially the epoxy glue are all qualified in a QFN 5x5mm package. Related studies suggest that BLT has great effect in preventing die attach delamination. Thicker BLT can accommodate more stress due to coefficient of thermal expansion (CTE) mismatch between silicon die and lead frame materials.

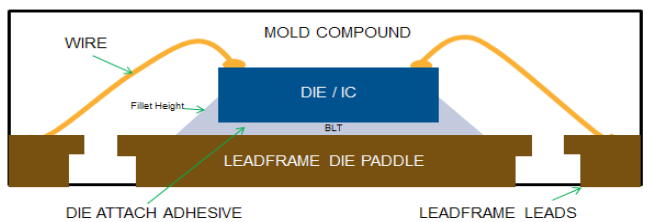

Figure 1. Cross-section drawing of a QFN package.

This paper aims to share and discuss the finite element modeling and simulation of epoxy glue bond line thickness (BLT) and fillet height combinationsof a QFN package die attach. The actual experimental validation performed using Moisture Sensitivity Level (MSL) test and Thermal Cycle stress test would also be presented.

2.0 REVIEW OF RELATED LITERATURE

2.1 Epoxy Die Bonding

Die Bonding is the process of attaching semiconductor die to a lead frame or substrates carrier. The process starts with picking the die from a wafer. The most common method is to push the target die from the tape with an ejector pin and at the same time it is picked by a vacuum tool or pick-up tool then placed and aligned to the pad of the lead frame or substrate carrier using different die bonding techniques. One of the most preferred techniques mainly due to its flexibility, cost effectiveness, low curing temperature, can be used for wide range of die sizes and can be easily reworked is the Epoxy Die Bonding,[2] which uses an epoxy glue. The epoxy glue is dispensed on the pad of lead frame or substrate carrier then the die placed on top of it. The package needs to be heated at elevated temperature to cure the epoxy glue properly. This process uses adhesives such as polyimide, epoxy and silver-filled glass as die attach material to mount the die to the die pad. The mass of epoxy climbing on the edges of the die is known as fillet. Excess of die attach fillet results in die surface contamination. Epoxy adhesives are electrical insulators and poor thermal conductivity but gold and silver materials are filled in to improve it.

2.2 Die Attach Bond Line Thickness (BLT)

In many studies, die attach BLT[3] has a major role in reducing the stress development since the adhesives can accommodate the stress developed due to the coefficient of thermal expansion (CTE) mismatch between silicon die and lead frame or substrate carrier. Thinner BLT results in high stressin the package. BLT is being measured by the distance from the carrier die paddle to the bottom of the die as illustrated in Figure 2. Typically, BLT is 0.5 – 2.0mil (around 12-50µm) and usually the measurements are not the same at all four corners and the computation to get the BLT is the average of BLTs at four corners of the die as illustrated in Figure 3.

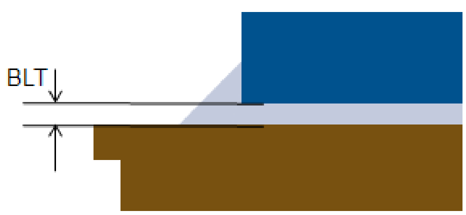

Figure 2. Bond line thickness (BLT) reference measurement.

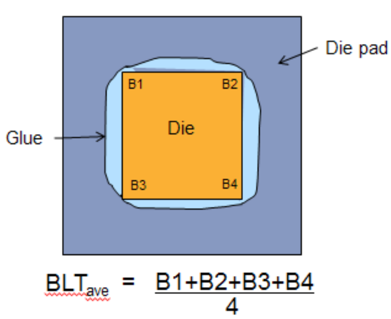

Figure 3. Measuring BLT during in-line assembly process.

2.3 Die Attach Fillet

Die attach fillet is an excess die attach adhesive climbing on the edge of the die during die attach process. The basic purpose of this die attach fillet is to anchor or provide mechanical strength along the die edges. Fillet height is being measured in percentage of the epoxy glue height relative to the die thickness as illustrated in Figure 4.

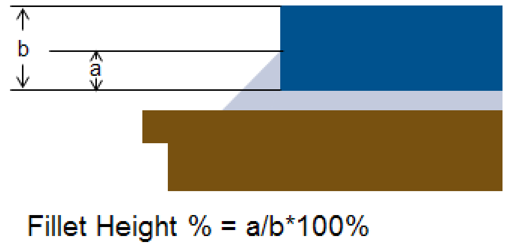

Figure 4. Fillet height reference measurement.

2.4 Die Attach Delamination

Delamination in semiconductor plastic packages often happens in many interfaces within the package itself, which is mainly caused by mismatch of the coefficient of thermal expansion (CTE) between interfaces of two materials within the package. Die attach delamination in a QFN package is the separation of die attach adhesive to silicon die and lead frame die pad. Die attach delamination will reduce the total contact area of silicon die to the lead frame die pad and it will increase the package thermal resistance that could lead to early thermal shutdown of the device which uses and expose pad to dissipate heat.[4]

3.0 EXPERIMENTAL SECTION

3.1Package Finite Element Modeling and Simulation

Thermo-mechanical modeling and simulation of the QFN package was conducted first using a 3-D model. Then a 2-D model was used to study the different BLT and fillet height combinations using a set of materials listed in Table 1. These are the loading and assumptions:molding compound is considered stress-free at 175°C with uniform temperature conditionand package is cooled down to room temperature and also to -65°C for the lowest temperature condition during thermal cycling.

Table 1: Material Properties Used in the Simulation.

Material	CTE (ppm/°C)	Elastic Modulus (MPa)	Poisson's Ratio
Die	3.0	169000	0.23
Lead Frame	17.7	110000	0.34
Glue	α1 = 40 α1 = 140 Tg = 175°C	5300	0.30
Mold	α1 = 8 α1 = 32 Tg = 110°C	21240	0.25

The package size was 5x5mm and the die size used was around 2x2mm. The BLT values considered were 5um, 15um, 25um and 35um. The fillet height values were 0%, 25%, 50% and 75%. The combinations of BLT and fillet height being studied are shown in Figure 5. These combinations were modeled and four types of stresses were being analyzed: (1) Glue Tensile Stress (S1), whichis related to epoxy glue crack; (2) Interface Shear Stress(Sxy), which attempts to cause the two material interfaces to slide against each other; (3) Interface Peel Stress (Sy), which pulls interfaces apart and normal to the interface; and(4) Effective Interface Stress, which is used as indicator that combines the effect of interface shear stress and peel stress and can be computed as

$$\sigma_{eff} = \sqrt{\sigma_{peel}^2 + 0.6 \cdot \sigma_{shear}^2}$$

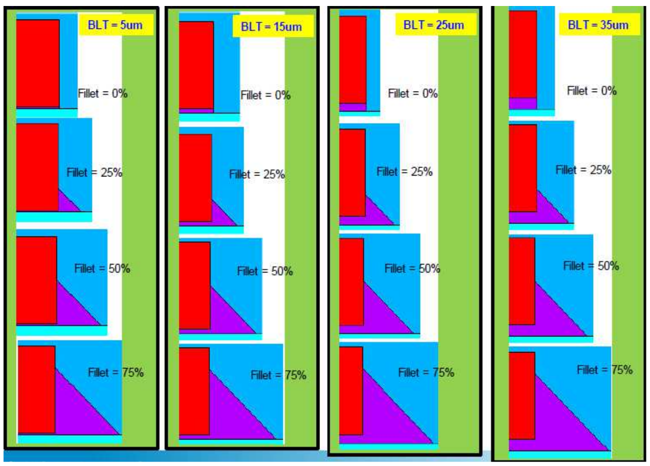

Figure 5.BLT &fillet height combinations.

3.2 Prototype Package Stress Test Assessment

A prototype run of Quad Flat No-lead (QFN) package with 5x5mm body size and die size of about 2x2mm was conducted. The assembled package samples, with all 0-hr buy-off data within the requirements, were subjected to moisture soak (MSL 3) followed by 3x reflow cycles at 260°C and then thermo-mechanical (TC) stress tests. After then, sample units were assessed through Scanning Acoustic Microscope (SAM), Cross-section and Scanning Electron Microscope (SEM) Analysis.

4.0 RESULTS AND DISCUSSION

Modeling and simulation results show good correlation with crack or delamination occurrence. The 3-D modeling indicates a "frowning" warpage (Figure 6) at cold temperature during the thermal cycling test and highest glue tensile stress areas are located at the edges (Figure 7). The 2-D modeling results also correlates well with the location of delamination initiation and crack location as clearly shown in Figure 8. The crack propagation path of glue is consistent with the location of high glue tensile stress areas. This indicates that the glue strength is not anymore able to withstand the resulting glue tensile stress. The glue-leadframe interface delamination is also at the high shear/peel (interface) stress areas.This means that with the resulting interface stress, the glue-leadframe adhesion strength is not anymore able to keep the interface in contact.

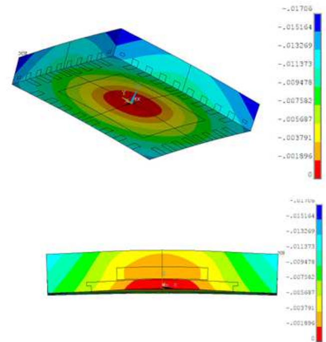

Figure 6.Warpage contour plot of the 3-D showing "frowning" warpage.

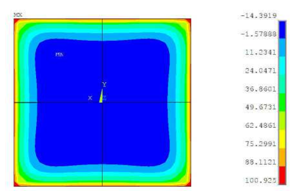

Figure 7. Glue stress contour plot of the 3-D model showing high stress areas at the edges.

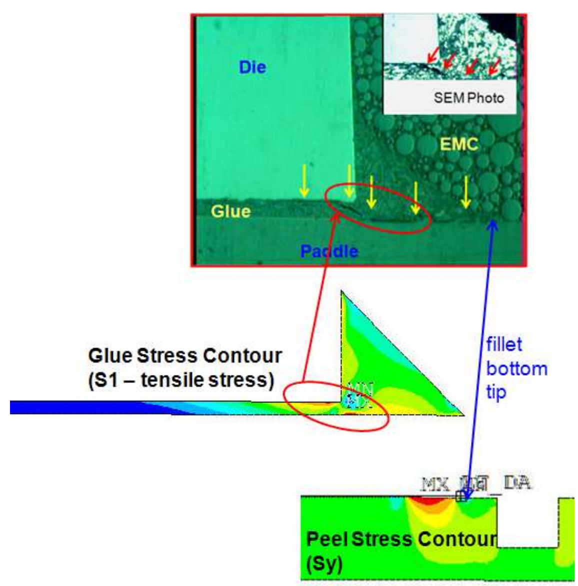

Figure 8. Actual delam/crack location vs stress results.

Forthe glue tensile stress, results are summarized graphically in Figure 9.At 0% fillet height, glue stress is quite high for all BLTs. But at 25% fillet height, there is a decreasing trend of glue stress as BLT increases.For each BLT, glue stress tends to be consistently lower at around 25% fillet height.

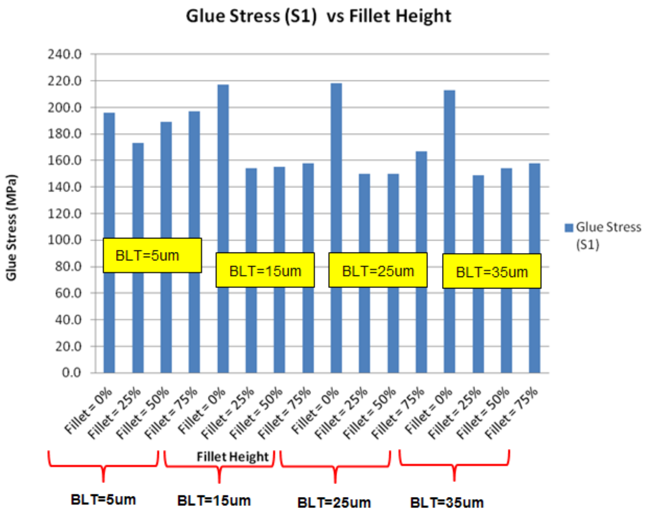

Figure 9. Glue tensile stress simulation results.

The interface shear stress results are summarized in Figure 10. At all BLT values considered, trend shows that shear stress consistently increases as fillet height increases. But shear stress tends to be decreasing with increasing BLT.And for the interface peel stress results (Figure 11), at 25% fillet to 50% fillet, stress consistently decreases also as BLT increases.In addition, it can be observed from the effective interface stress results that the interface stress generally decreases as BLT increases (Figure 12).

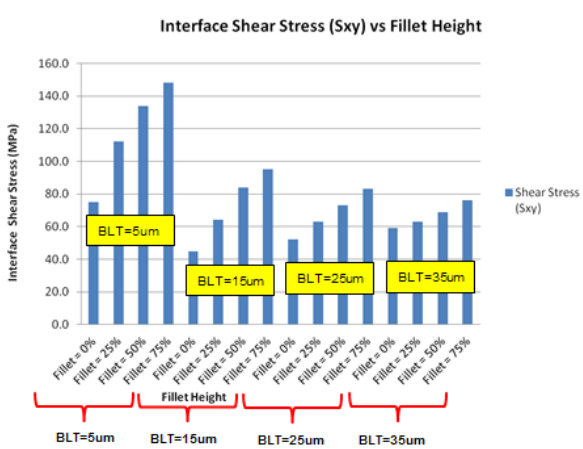

Figure 10. Interface shear stress simulation results.

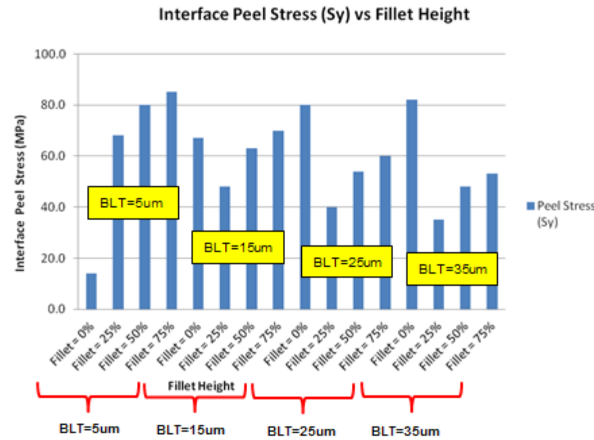

Figure 11. Interface peel stress simulation results.

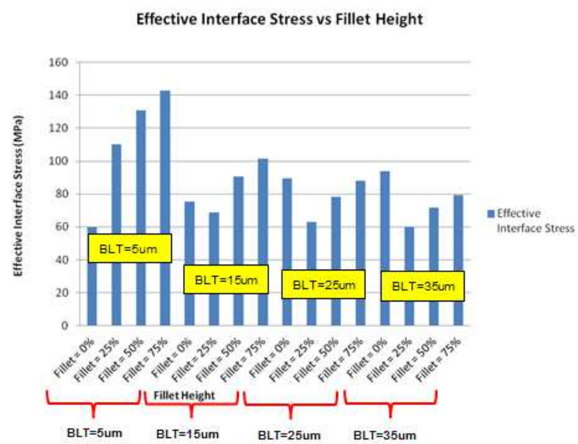

Figure 12. Effective interface stress simulation results.

Based on simulation results of all defined stresses, it can be stated that stresses are generally lower at around 25% fillet height as compared to 0% fillet and 75% fillet height. At 25% fillet height, glue tensile stress and the interface stress decrease as BLT increases.

From actual evaluation, Figure 13 shows the development of delamination propagation during thermal cycling using SAM and Figure 14 shows its cross-section and SEM analysis to validate the SAM results.

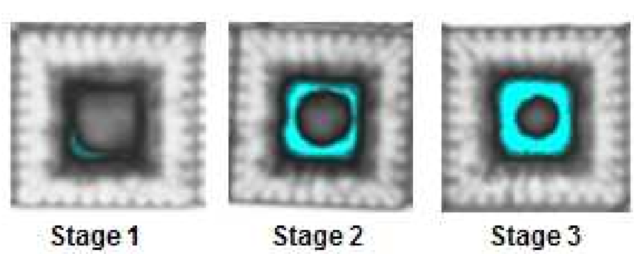

Figure 13. The development of delamination during thermal cyling.

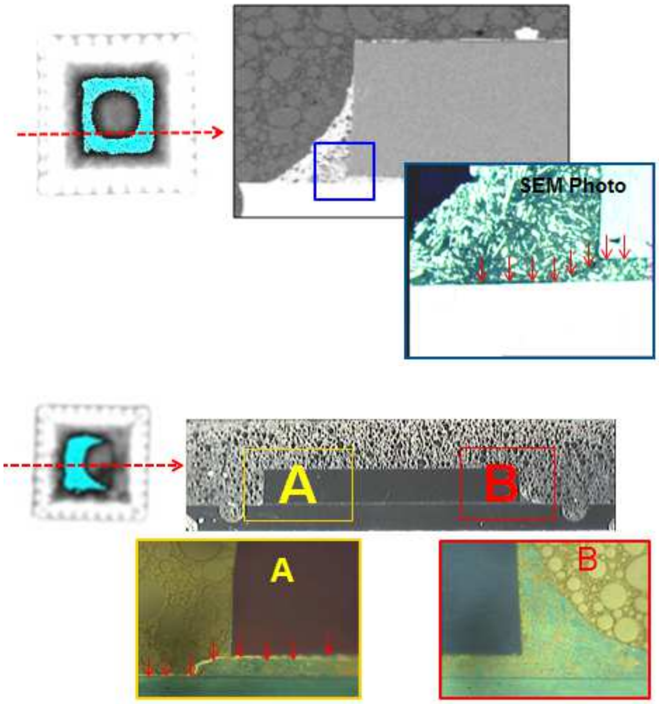

Figure 14.Cross-section and SEM photo of a sample unit with delamination.

The actual evaluation confirmed the modeling and simulation stress trend in terms of the different BLT and fillet height combinations. Delamination and glue crack or die attach failure were observed with the representative unit having 15µm BLT and 0% fillet height as shown in Figure 15. For those with fillet, the general observation was that the worst delamination was encountered onthose units with higher fillet measured as compared to those with lower fillet. This also agrees with the observation by Yang, et al [5] that several failed units they examined in their study were having excessive fillet height.

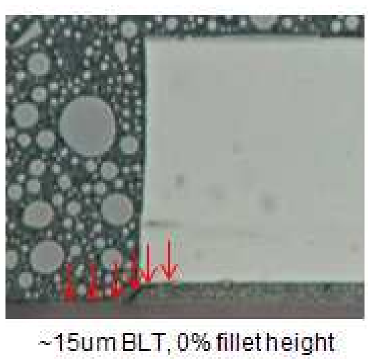

Figure 15. Cross section result of unit with ~15µm BLT and ~0% fillet height.

Table 2 shows the summary of the selected combinations and their results on actual cross-sectioning validations that also correlate with the simulated combinations. Figure 16 shows the actual cross-section results of the selected best combinations.

Table 2: Selected Combinations Results Summary

BLT, um	Fillet Ht, %	SAM Results	Cross-section Results
15	25	No delamination	No cracks
25	25	No delamination	No cracks
35	25	No delamination	No cracks

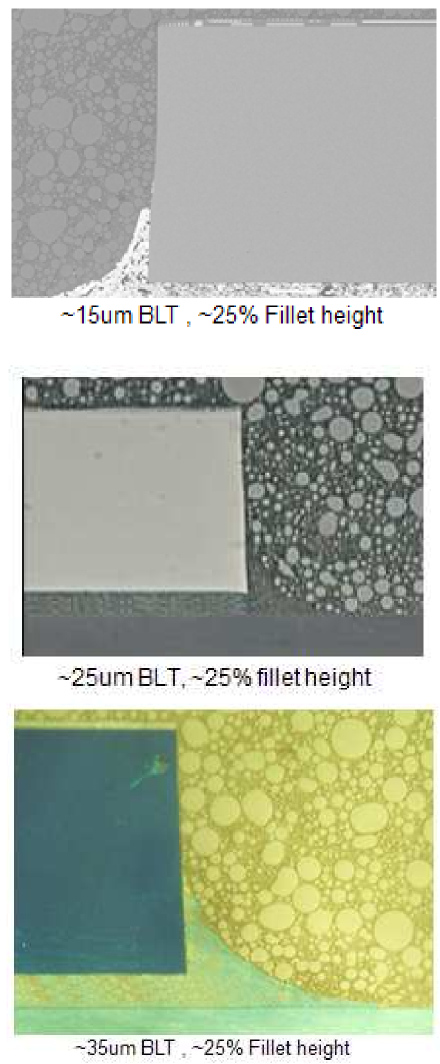

Figure 16. Cross section results of selected best combinations.

5.0 CONCLUSION

From the modeling and experimental results, it can be concluded that the fillet and BLT combinations significantly affect the die attach delamination performance of a QFN IC package during MSL and thermal cycling. Increasing fillet height beyond its optimum value would not help create a robust IC package but instead increase the risk of delamination. Very thin glue BLT and 0% fillet would also increase the likelihood of package failure.

And also it is shown that modeling or virtual prototyping could provide a better understanding of the interface delamination mechanism, find optimum BLT and fillet height as well as locate high stress areas that correlate with actual package or die attach failures.

6.0 RECOMMENDATIONS

Based on this study, it is recommended to control bond line thickness (BLT) and fillet height at their optimum values in order to avoid die-attach interface delamination and crack propagation.

To understand delamination failure mechanism, virtual prototyping or FEA modeling and simulation could be used to find optimum die attach BLT & fillet height values and thus minimize actual evaluation runs.

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7.0 ACKNOWLEDGMENT

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9.0 ABOUT THE AUTHORS

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