

Die attach and package reliability



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THE EFFECTS OF DIE ATTACH PROPERTIES ON DELAMINATION IN EXPOSED-PAD LQFP Tay, SweeTeck Assembly Packaging Technologies, Singapore
Advanced Applied Adhesives, San Diego, CA, USA com Die attach material has direct impact on package reliability. Its mechanical properties affect the interfacial stresses in the package.

Its moisture stability and hot adhesion determine if it has sufficient adhesion to pass moisture soak and 260°C reflow without causing delamination and package crack. Its water extractable cations can form electrolytic solutions to trigger bond pad corrosion process and its anions cause dendrite growth.

While the ion induced problems are becoming rare with modern resin purification technologies, and the occurrence of package crack in 260°C reflow reducing with the advance in mold compound technology, the interfacial delamination remains the main cause of package failure today.

This paper demonstrates how the die attach mechanical properties affect the interfacial stress in a large exposed-pad LQFP package with the aid of finite element analysis and outlines the approaches taken to help eliminate delamination. INTRODUCTION Exposed-pad LQFP is made with a deep downset leadframe such that the bottom side of the die pad is exposed. This enables the pad to be soldered directly to the board for better heat dissipating efficiency.

Smaller exposed pad LQFPs have been in volume production for several years while the large ones continue to have delamination problem because of the higher CTE mismatch stress from the larger asymmetrically molded mold cap. DA1 Die 65? m Die back delamination at die corner Copper pad
Take the 28 x 28 mm exposed-pad LQFP for example, even achieving

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delamination free time-zero thru scan is a challenge. This paper uses finite element analysis to help analyze the stresses associated with the initial failures of the exposed-pad package and attempts to solve the problem by reducing stress and enhancing adhesion to the problem areas. Figure 2: Time zero die back delamination of DA1 INITIAL TEST DA1 with properties listed in table 1 was used for the initial evaluation of a 28 x 28 mm ex-posed-pad LQFP. After post mold cure, all the parts showed die corner delamination in thru scan as in figure 1.

Figure 2 shows the cross section photo of a failed part. The die corner delamination is at the die back / die attach interface. To study the delamination problem, Algor, a commercial finite element analysis software was used to calculate the stresses on the die back. Table 1 shows the mechanical properties of the materials. Size (mm) Modulus (GPa) Poisson's Ratio CTE (ppm/°C) Si Die 8 x 8 x 0.280 130 0.

28 2.8 Cu 10 x 10 x 0.120 117 0.3 17 DA1 8 x 8 x 0.

050 4.2 0.3 174 EMC1 28 x 28 x 1.4 27.5 0.

3 14.7 Table 1: FEA modeling with DA1 Static stress with linear material model was used for the analysis. Default nodal temperature was set at 25°C and the stress free reference temperature at 175°C, cure temperature of the mold compound. All the materials were considered to be isotropic and homogeneous. Figure 3 shows the isometric view of the three-dimensional model with DA1 in 128-color spectrum. Page 2 of 6 Figure 5: Isometric view of die top with DA1 307 MPa 171 MPa Figure 6: Isometric view of DA1 top

surface Figure 4: Isometric view of die bottom with DA1 257 MPa Figure 3: 3D model of the LQFP package with DA1.

Displacement scale factor set at 5% of model size Figure 4 shows the stress distribution on the back of the die at 25°C in standard 7 color palette. The die has a negative curvature and the die back corners that correspond to the die back delamination failure are the stress concentration zones. The von Mises stress is 257 MPa. The maximum stress on the die is on the top surface. Figure 5 shows the stress distribution. The red corners have the maximum stress of 307 MPa which is higher than the die back corners.

It did not result in die top delamination in the time-zero CSAM either because the die back delamination released the stress before the die top saw the maximum stress, or the adhesion of the mold compound to the die top was higher than the maximum stress. Since we are dealing with die back delamination, we shall ignore the die top stresses in this study. Figure 6 shows the stress distribution on the die attach material. The stress at the corners that corresponds to the die back failure is 171 MPa. SECOND TEST DA2 was formulated with lower modulus and enhanced adhesion to silicon as an attempt to overcome the die back delamination.

Table 2 compares the modulus and CTE of the two die attach materials. As shown, DA2 has one-quarter of the modulus and similar CTE as DA1. Modulus (GPa) 175°C - 25°C CTE (ppm/°C) DA1 4.2 174 DA2 1.0 173 Figure 10: DA2 showed spot delamination after MSL 3 260°C Figure 9: DA2 showed no delamination at time zero Figure 7: Isometric view of die bottom with DA2 233 MPa Figure 8: Isometric view of DA2 top surface 40 MPa Table 2:

Mechanical properties of DA1 and DA2 FEA was performed on DA2 to compare the die back and die attach stresses.

Figure 7 shows the stress distribution on the back of the die. The stress at the die back corner is reduced to 233 MPa. Figure 8 shows the stress distribution on the top surface of DA2 die attach layer. Maximum stress at the corner is reduced to 40 MPa. Table 3 compares the stresses using DA1 and DA2 on the de-laminated area.

As shown, the low modulus DA2 reduces the die back corner stress by 9% and die attach stress by 77%. Die back corner (MPa) Die attach top corner (MPa) DA1 257 171 DA2 233 40 Reduction 9% 77% Table 3: Stress reduction by DA2 Parts were built with DA2 to verify if the enhanced adhesion to silicon coupled with the stress reduction were good enough to solve the time zero delamination. Figure 9 shows the time zero SAT. All the parts were delamination free. The results were encouraging as they matched the theoretical prediction.

The parts were then subjected to MSL3 260°C testing and scanned for delamination. 87% of the parts were free of de-lamination in the die attach area and 13% of the parts showed spot delamination in the center of the pad as in Figure 10. Cross-section analysis showed the spot delamination was between the die attach material and the center of the pad top. MORE STRESS SIMULATIONS Figure 11 shows the stress distribution on the die pad with DA2. The stresses are concentrated at the areas correspond to the die corners and die edges. For easy reference, we shall refer to these locations as “ pad top corners” and “ pad top edges” for the rest of the discussions in

this paper; even though they are not exactly at the corners and edges of the pad.

In addition to the stress concentrated pad top corners and edges, the pad also has a high stress circle in the center of the pad which corresponds to the area of spot delamination. Page 3 of 6 Figure 11: Isometric view of pad top with DA2 199 MPa von Mises Stress vs DA 0 50 100 150 200 250 300 350 MPa 1 DA1 2 mil BLT 2 DA2 2 mil BLT 3 DA3 2 mil BLT 4 DA4 2 mil BLT 5 DA2 4 mil BLT Figure 13: Stress vs DA type and BLT Figure 12: Exploded perspective view at 10% displacement scale factor with DA2. Mold cap hidden. DIE DA2 Figure 12 is a perspective exploded view showing how the die, die attach and die pad warp inside the molded package and the stress distribution using the same stress range. The displacement scale factor is increased to 10% of the model size to exaggerate the deformation.

die corner die edge DIE PADAs shown in figure 12, the die pad is raised at the die corners and the die edges but deflected downward in the center. The die attach in the center of the pad is under tensile stress. FEA was performed on two other die attach formulations (DA3 with medium modulus but lower CTE, DA4 with lower modulus but higher CTE), and also on DA2 with thicker bondline to see if the pad top center stress could be further reduced. Table 4 compares the modulus and the CTE of the die attach materials DA Material Modulus (GPa) 175°C - 25°C CTE (ppm/°C) DA1 4.

2 174 DA2 1. 0 173 DA3 2. 1 119 DA4 0. 365 233Table 4: Mechanical properties of die attach materials Table 5 summarizes the stresses in 5

groups and figure 13 shows the stresses as bar chart. # DA BLT (mil) Pad Top Corner Pad Top Edge Pad Top Center Die back corner DA Top corner

Group #	DA	BLT (mil)	Pad Top Corner	Pad Top Edge	Pad Top Center	Die back corner	DA Top corner
1	DA1	2	269	229	190	257	171
2	DA2	2	255	233	199	233	40
3	DA3	2	225	212	201	223	59
4	DA4	2	265	246	193	235	20
5	DA2	4	303	263	183	247	40

Table 5: Stress vs DA type and BLT Group # 1 is our first test.

The 4. 2 GPa DA1 that failed die back corner delamination before MSL soak has the highest die back corner and die attach stresses among the 5 groups. Group # 2 is our second test. The 1. GPa DA2 that had zero delamination failure at time zero but spot delamination on the die pad center after MSL 3 260°C reflow has higher pad top stress than DA1.

Group # 3 is a simulated group with a 2. 1 GPa DA3. It has higher pad top center stress than group # 2 but its lower CTE Page 4 of 6 von Mises Stress0 50 100 0 0 0 0 0 0 Pad Top Corner Pad Top Edge Pad Top Center Die back corner DA Top corner MPa 15 20 25 30 35 40 significantly lowers the stresses at the pad top corners and edges. It also has lower die back corner stress. This material would be the material of choice if the delamination is at the pad corners or edges. However, since our task is to reduce pad top center stress, DA3 is not a good candidate.

Group # 4 is a simulated group with DA4. This material has lower modulus but higher CTE than DA2. It has half the die attach stress and lower pad top center stress. However, it increases the stresses at the pad top corners/edges, and the die back corners. Group # 5 is a simulated group with DA2 at 4 mil bondline thickness.

It produces the lowest pad top center stress of the five groups, but also the highest stresses at the pad top corners/edges and the die back corners. DA1 2 EMC12 DA2 2 EMC13 DA3 2 EMC1 4 DA4 2 EMC15 DA2 4 EMC16 DA2 2 EMC2 7 DA2 2 EMC38 DA2 2 EMC49 DA2 4 EMC4

Figure 14: Stress vs DA type, BLT and EMC type Copper pad DA2

Figure 15: DA2 showing sign of adhesive failure after temperature exposure

The stress simulation suggests that while group # 4 and 5 may help to fix the pad top center delamination, they may result in delamination elsewhere. FEA was also carried out with three other commercially available green mold compounds for LQFP to see if changing the mold compound could help to reduce pad top stresses. The stresses are listed as group 6 to 9 in table 6, and figure 14 depicts the stresses as bar chart. Among group # 6 to 8, only group # 7 which uses a low modulus but high CTE EMC3, has a lower pad top stresses than group # 2. However, it pushes the die back corner stress to 352 MPa which may cause die back delamination.

In summary, increasing bondline thickness of DA2 (group # 5 and 9), changing to lower modulus but higher CTE die attach material (group # 4) or mold compound (group # 7) will re-duce the pad top center stress. However, the higher pad top corner and edge stresses from thicker bondline and the high die back corner stress from higher CTE mold compound are undesirable.

#	DA	BLT (mil)	EMC	Pad Top Corner	Pad Top Edge	Pad Top Center	Die back corner
1	DA1	2	EMC1	269	229	190	257
2	DA2	2	EMC1	255	233	199	233
3	DA3	2	EMC1	225	212	201	223
4	DA4	2	EMC1	265	246	193	235
5	DA2	4	EMC1	303	263	183	247
6	DA2	2	EMC2	262	239	205	213
7	DA2	2	EMC3	209	199	185	352
8	DA2	2	EMC4	238	224	200	

229 41 9 DA2 4 EMC4 282 249 183 242 40 Table 6: Stress vs DA type, BLT and EMC type To avoid solving one delamination and create another, the decision was to stick to the CTE and modulus of DA2 but improve its adhesion to copper pad. ADHESION IMPROVEMENT Unmolded parts made with DA2 were ramp cured to 175°C and held at temperature for 60 minutes. The parts were then subjected to 4 hours of 175°C oven bake for post mold cure followed by 3 x 260°C reflow to simulate the temperature exposure seen by the die attach material during assembly and solder reflow. The parts were then tested for 270°C die shear and 25°C tensile pull. While DA2 still had very strong die shear and tensile pull strength after all the temperature treatments, its failure mode started to degrade from cohesive failure (break within bondline) after PMC to varying degrees of adhesive failure (break at interface) after 3 x 260°C reflows. Figure 15 shows one of the worse parts that had a large area of bare copper exposed after adhesion test.

. Several versions of DA2 with improved adhesion to copper were developed. But since they involve technologies which patent process has not yet been completed, they are considered proprietary and will not be described in this paper. Page 5 of 6 The improved versions were tested for the same temperature simulated adhesion tests. Figure 16 shows one of the improved materials, DA5, that maintained cohesive failure throughout the temperature treatments. Silicon fragment DA5 Figure 16: DA5 maintained cohesive failure after temperature exposure The cohesive failure mode after 3 x 260°C temperature reflow suggests DA5 is less susceptible to interfacial delamination during MSL3 260°C.

The material has similar CTE and modulus as DA2 and will have similar stresses in the package. Since DA2 already exhibited near zero MSL3 260°C delamination, the improved adhesion (to copper) DA5 may be the answer to the die pad delamination problem. CONCLUSIONS Several conclusions can be drawn from this study: 1. The modulus and CTE of the die attach material have a huge effect on the stresses and therefore the delamination failures of the exposed-pad package 2. However, we cannot generalize the effect of a die attach material in a molded package based on its modulus or CTE alone.

For example, the 365 MPa DA4 produces a lower pad top center stress than the 1. GPa DA2. But it is incorrect to say higher modulus die attach will impart higher stress to the pad top center as the 4. 2 GPa DA1 also has lower pad top center stress than DA2. This is because stress is strain x modulus, and strain in our case is (change in temperature) x (difference in CTE).

Therefore stress is proportional to (difference in CTE) x modulus. We have to consider the modulus and CTE of various components and the geometry of the package as a whole and evaluate the stresses on a case-by-case basis. 3. Figure 14 shows that with the real-world materials, which are either low modulus and high CTE or vice versus, lowering stress at some locations leads to increased stresses elsewhere.

While a low modulus AND low CTE die attach material may help to reduce the see-saw effect, making such material is a real challenge. 4. Given the constraints of the current die attach materials and mold compounds; we can only optimize the stresses to a certain level. The ultimate solution is still in

enhancing the retained die attach adhesion to a particular interface, after all the hydrothermal treatments, to overcome stress. .

It is interesting to note that increasing DA2 bondline thickness from 2 to 4 mil has similar but stronger effect on stresses as using a lower modulus but higher CTE DA4. ACKNOWLEDGMENTS The author would like to thank Debbie Forray, Frank Mizori and Steve Dershem for their valuable support and contributions on data collection and material improvements. REFERENCES 1. Zhang, J. and Huneke, J.

“ Analysis of Geometry Parameter Effects of Die Attach Adhesives in a PBGA Package with Finite Element Method”, Henkel Loctite Technical Paper. 2. Zhang, J. , Forray, D. nd Huneke, J, T, “ Theoretical and experimental analysis on the effect of material properties of die attach adhesives in molded plastic packages”, Proceedings of Nepcon West, 1999, pp. 1699-1708.

3. Sauber, J. “ Modeling of Die Surface Features on Integrated Circuits to Improve Device Reliability”, Digital Equipment Corporation Technical Paper.

4. McCluskey, P.

“ Fatigue and Intermetallic Formation in Lead Free Solder Die Attach”, Proceedings of IPACK'01, the Pacific Rim/ASME International Electronic Packaging Technical Conference and Exhibition, July 8-13, 2001, Kauai, Hawaii, USA