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Root Cause Mechanism for Delamination/Cracking in Stacked Die Chip Scale Packages

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Abstract – A key challenge in the development of ultra-thin stacked die chip scale packages is to meet package performance requirements without delamination. Interfacial delamination and cohesive failure are particular concerns. The root cause of this type of failure is difficult to discern, even with extensive root cause analysis and focused DOEs.

Through comprehensive simulation and material characterization, three key parameters were identified which affected the package performance, i.e., substrate thickness, reflow time and substrate diffusivity. The root cause model established the relationship between moisture uptake, material properties such as diffusivity and porosity, and vapor pressure buildup. Two scenarios with regard to package behavior during soldering reflow are predicted.

INTRODUCTION

A key challenge for developing ultra-thin stacked-die chip scale packages (CSP) is to meet the package reliability requirements without delamination in the package. The higher reflow temperature required for lead-free packaging results in increased reliability concerns for these plastic packages.

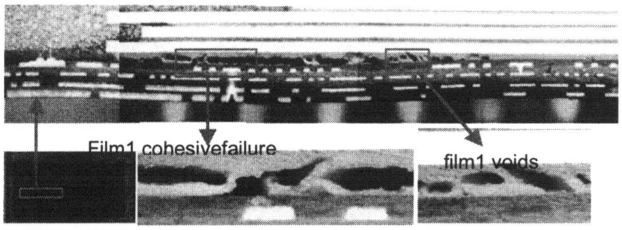

Figure 1. After L3 preconditioning, massive cohesive delamination was seen in the first layer of die attach film (film 1). The cohesive delamination is a consequence of void growth and coalescence induced by vapor pressure during the reflow process.

Cohesive delamination has been observed in the first layer of die-attach film (film 1), as seen in Figure 1. Failures were detected by TSAM after Level 3 pre-conditioning. The pre-conditioning involves soaking at the constant temperature/moisture, and then to a reflow process. The failure rate depends on the reflow profiles even with the same peak temperature at 260^{0}C. Figure 2 illustrates different reflow profiles, both satisfying JEDEC standard. The delamination rate was dramatically less in the FM case versus the SH case.

After a careful review of the failure in the die attach material and various DOEs to attempt to determine root case a new approach was examined. It was postulated that the failure was the result of vapor pressure exceeding the strength of the materials and interfaces in the package. To evaluate this theory the moisture properties of the packaging materials were determined and the stress levels in the package were modeled.

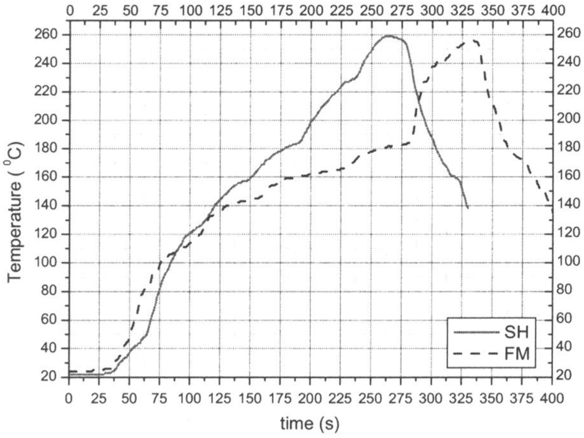

Figure 2. Two reflow profiles both meet the JEDEC standard. The main difference is that FM one ramps much slower up to the temperature peak compared to SH one.

PACKAGE MATERIAL PROPERTIES AS A FUNCTION OF MOISTURE

The effect of moisture on material properties and moisture transport in package materials were evaluated. The properties of the die attach material were examined. Figure 3 plots the Young's Modulus of die attach film as function of temperature with and without moisture. It can be seen that the Tg drops significantly after moisture absorption. Figure 4 shows the moisture weight gain curve for a 30µm die attach film at 30°C/70RH%. It shows that the film is saturated within 5 minutes even at room temperature. The diffusivity at the reflow temperature (e.g. 260°C) is an order higher than the data in literature (e.g. [1], [2]). This is an important finding because it implies that moisture escape plays a more significant role then indicated by the ambient diffusivity data.

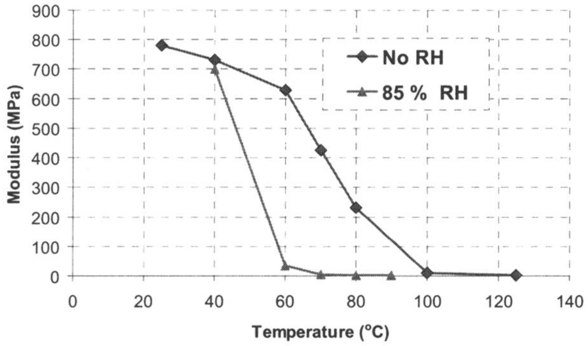

Figure 3. Modulus as function of temperature for DA film

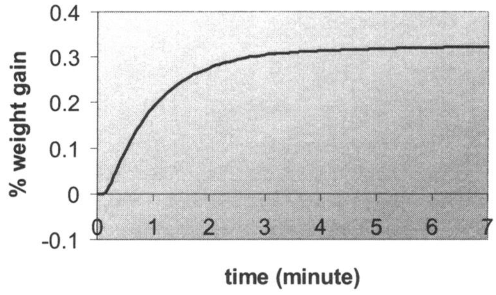

Figure 4. 30um die attach film moisture weight gain curve at 30°C/70RH%

Figure 5 plots the saturated moisture concentration at 60RH% and 30RH% with various temperatures. It confirms that the saturated moisture concentration for BT material is independent of temperature level up to 80°C.

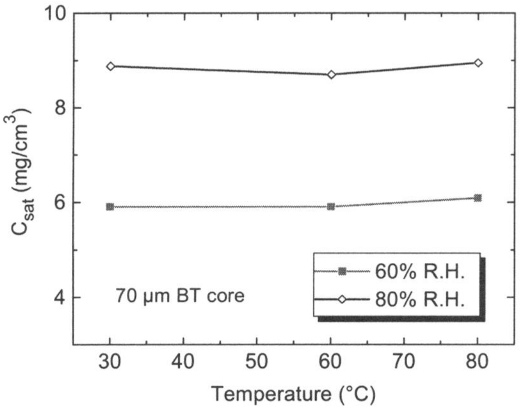

Figure 5. Saturated moisture concentration as function of temperature

Representative plastic package material moisture diffusivity and solubility constants are listed in Table 1.

Table 1. Material properties at 60^0C/60RH

	DA Film	BT-Core	SR	MC
Diffusivity ($10^{-12}m^2/s$)	29.3	0.514	1.3	0.152
Solubility (10^{-4} kg/m^3.pa)	3.92	3.92	13.3	2.08

MOISTURE MODELING RESULTS (MOISTURE CONCENTRATION AND VAPOR PRESSURE)

Vapor pressure is directly related to temperature and moisture concentration which may decrease during reflow due to moisture diffusion out of the package. In this section, the moisture diffusion is used to explain the drastic delamination performance for different types of substrate. The details of the model are not discussed, only the results which incorporated the materials properties noted in the earlier section.

Figure 6 shows the moisture distribution after 96 hours for different substrates. The results show that the substrate and the die attach film 1 are fully saturated for different substrates. The above results show that the initial moisture concentration in die attach film 1 (area enclosed by dashed line, thickness being exaggerated for visual clarity) is same for both substrates right after soaking. From the moisture contour plot, it can also be observed that moisture diffuses very slowly in the molding compound (MC). Therefore, inside film 1 moisture is mainly from the diffusion through the substrate, and other layers of die attach film is from molding compound.

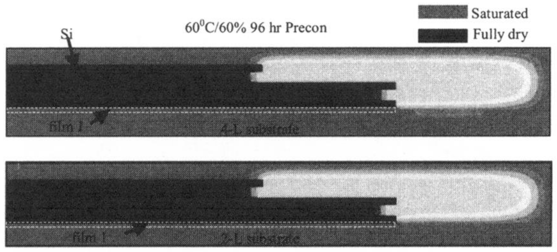

Figure 6. After 96 hr 60^0C/60% Precon, film 1 is saturated in both the 2-L substrate and 4-L substrate. Other layers of film are dry due to the moisture blocking Si, provided the other film layers initially are dry.

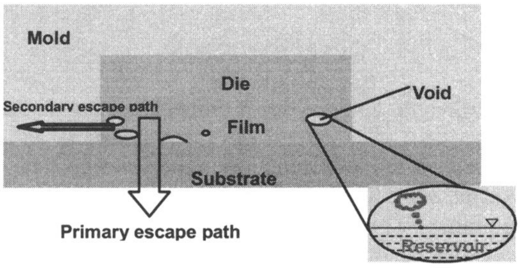

Figure 7. Schematic of diffusion path during reflow (not to scale for visual clarity). Initial tiny voids acting like water reservoir giving high vapor pressure which may cause cohesive delamination during reflow.

During reflow, the moisture absorbed during soaking acting like water reservoir (Figure 7). At high reflow temperature, water vaporizes giving high vapor pressure, which may lead to cohesive delamination. At the same time, it escapes by diffusion.

Two scenarios of vapor pressure build up can predicted. These two scenarios are illustrated in Figures 8 and 9, respectively.

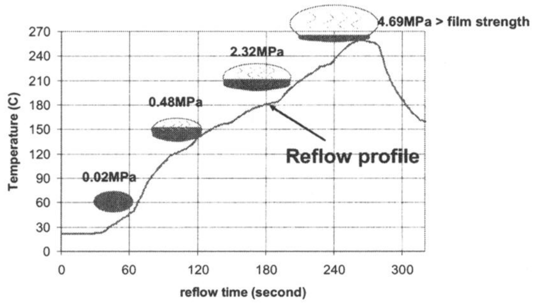

Figure 8. Scenario 1: vapor pressure buildup during reflow

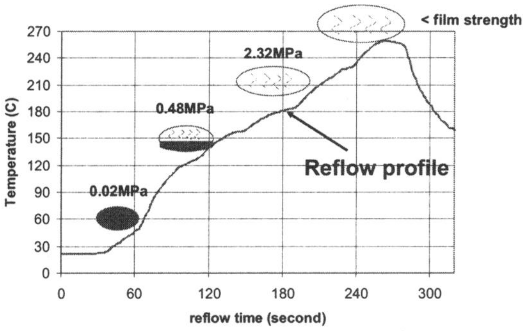

Figure 9. Scenario 2: vapor pressure buildup during reflow

The delamination performance difference lies in the moisture loss during the reflow process. If the diffusion time scale τ is much shorter than the reflow time, moisture can diffuse out of the package for both substrates; if the diffusion time scale τ is much larger than the reflow time, moisture can not diffuse out of the package for both substrates. If either of the above scenarios is true, then moisture escape through the substrate can not explain the substrate dependent delamination performance difference between the different substrates. Only when the diffusion time scale is comparable to the reflow time, should the moisture diffusion be a concern during reflow. The most diffusion resistant organic material inside the substrate is BT core. Hence, for thicker substrate, it takes more time to escape same amount of moisture to decrease the vapor pressure to a safe level and shows higher delamination rate. The moisture diffusion analysis also explains there is no cohesive delamination in other layers of film. Other layers of die attach films are sandwiched by dies, so the moisture absorbed during soaking is far from saturation. If the initial moisture level is low, there should be of no cohesive delamination.

Figure 10 plots the ratio of moisture concentration over the saturated moisture concentration in the die attach film. About 80% of the total saturated moisture can be lost in 6 minutes during reflow. There exists a critical moisture concentration, above which the delamination will occur. The diffusivity D, substrate thickness and reflow time are three critical parameters to control the residual moisture level in die attach material.

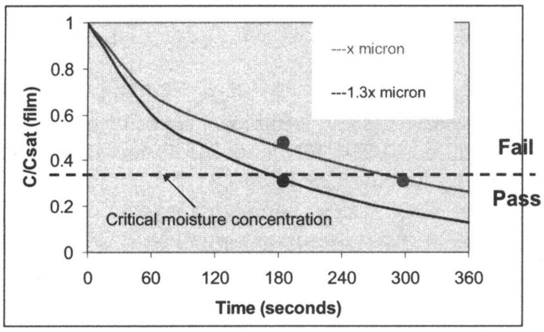

Figure 10. Moisture loss during reflow

Failure happens at high temperature where polymer has a larger CTE, thermal stress and hydrothermal stress inside the film are both compressive because the polymer expansion is constrained by the surrounding materials with relatively higher stiffness. It is unlikely for a material under compression to grow voids based on the cavitation theory. Meanwhile, the thermal stress and hydrothermal stress level inside the film is limited by the film modulus. A reasonable elastic deformation, say 3% strain, gives only ~0.03MPa. The finite element modeling confirmed the thermal stress inside the film is compressive and on the order of ~0.01MPa, which is far smaller than the saturation vapor pressure 4.7MPa at 260^{0}C. The moisture may diffuse out of the package during reflow. If 50% moisture is lost, the pressure still can be a few MPa, still much larger than the stress level by CTE mismatch and hydrothermal stress. So the CTE mismatch and hydrothermal stress effect can be neglected safely. Past results showed that if a substrate did not go through the soaking procedure, there was no delamination after reflow. Therefore, it can be concluded that the failure driving force is water vapor pressure at the high temperature.

For a reasonable initial void size ~1μm, the deformation falls into the elasticity controlled regime. The saturation vapor pressure (a few MPa) and low modulus of the film (1~2MPa) satisfy the cavitation condition, therefore, film may fail cohesively if the moisture concentration is high enough inside the film.

VALIDATIONS

A controlled experiment varying the substrate material components was evaluated to determine the effect on moisture related reliability performance. A substrate contains Solder Mask (SM)/BT core/Copper layer (Figure 11). The following parameters were varied (1) BT core thickness to study the thickness effect of the diffusion path on the delamination. (2) SM thickness to check its high solubility effect which makes it as a moisture reservoir. After fast preconditioning, the delam rate is monitored by TSAM.

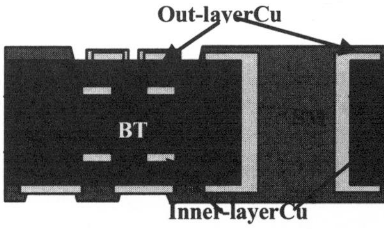

Figure 11. Schematic of substrate

Table 2 clearly demonstrates that the thicker the BT-core, the higher the delamination rate (Leg 1-4). The BT-core acts like a strobe controlling the moisture diffusion from film 1 out of the package. SM has higher solubility which accumulates more water during soaking. This explains even the BT-core thickness for Leg 5 is close to Leg3,4, it still has the highest delamination rate.

Table 2. Delamination rate for different substrate design.

Thickness (μm)	Leg1	Leg 2	Leg 3	Leg 4	Leg 5
Solder Mask	1x	1.02x	1.04x	1.04x	1.37x
Inner Cu density	0%	50%	50%	50%	50%
BT-Core	1y	1.09y	1.43y	1.47y	1.44y
Total	1z	1.20z	1.47z	1.47z	1.53z
Delam Rate	0%	7%	32%	47%	100%

Each leg sample size 240. relative thickness values shown (x-soldermask, y-BT core, z-total substrate thickness).

As shown in Figure 2, FM profile ramps to the temperature peak much slower than SH profile does. The slow ramp period from time 0s to 270s acts as an in-line baking prior to the temperature peak. More moisture will diffuse out of the package through the substrate for Folsom profile, which can significantly reduce the vapor pressure at the temperature peak. The understanding supports the delamination rate difference observed between ~7% for FM profile and ~80% for SH profile.

DISCUSSION

An important consideration is the cohesive strength of the DA materials in the package as it relates to the stress in the package induced by mechanical/material/moisture effects. If any of the materials in the package have lower cohesive strength than the stresses imposed during reflow there will be a risk of cohesive failure during reflow. When the materials have high modulus (e.g. > 50MPa), the cohesive failure has never been a concern. Instead, the failure always occurs at the interface [3], [4]. In that case, the adhesion strength at elevated temperature with moisture is a critical indicator for the package performance. However, for the materials with modulus at high temperature in the range of the saturated vapor pressure (4.7MPa at 260°C), the residual moisture concentration and the void size become the most critical indicators for reflow performance. The vapor pressure becomes a dominant driving force for the cohesive failure.

For thicker substrate packages the moisture loss along the substrate/DA material interface may not be significant during reflow, though significant amount of moisture in the exterior of package might be lost. However, for ultra-thin package with thinner substrate thickness there will be a significant moisture loss in DA materials. The thin package with very soft DA adhesive is very sensitive to the residual moisture and the reflow time. A few minutes bake could completely dry the package out. This is fundamentally different from thicker packages, where it takes a few hours or days to dry out the package.

In addition to the reliability related moisture effects described earlier there are also process related effects that show high correlation to moisture related phenomena. A key parameter that requires careful control is moisture bakeout and the queue time following moisture bakeout. This is particularly true for packaging materials that have fast moisture uptake rates. Moisture bakeout procedures should use JEDEC standards [9] as a baseline and tailor the queue time to the material properties to attain processes with good EOL yield. For materials that absorb moisture quickly and are subsequently encapsulated by a more impervious material there is the risk of trapped moisture that can result in EOL delamination.

Conclusions

The expansion of moisture in plastic packages during reflow results in large amounts of stress being generated in the package, and at the same time, a significant reduction of adhesion strength, which can result in delamination in the package. Thus an understanding of the moisture diffusion rates and maximum moisture loading for materials in plastic packages is important to attaining high reliability packages that do no delaminate at EOL or in reliability. Careful selection of package materials to minimize moisture uptake and maximize diffusion rates would improve package performance. Careful consideration of the moisture properties of the materials in the package is also important since this can affect the understanding of how moisture can be trapped in the packaged due to poor control of complete encapsulation of more absorbent materials before they can desorb moisture in the molding process if the encapsulant has high impedance to moisture release.

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