

Original Research Article

Improvement on Semiconductor Substrate Design with Package Modeling and Simulation for Mitigation of Delamination and Voids

ABSTRACT

This technical paper presents the challenges encountered in the development of a compact and thinner package that incorporates multiple or stacked dice in one. For the case of this paper, Die1 (bottom die) is smaller than Die2 (top die) and must be the first one to be die bonded, making the internal construction an unbalanced stacked dice. Typically, stacked dice is in pyramid layout, wherein a single large bottom die supports smaller top die. Nonetheless, success is measured when there is a solution to control or mitigate die attach voids and eliminate or significantly minimize delamination for unbalanced stacked dice as mentioned. Ultimately, the paper presents the understanding of the factors involved and the package design optimization approach used to produce a successful unbalanced stacked die in a thin package using thin substrate.

Keywords: Substrate design; planarized; delamination; DAF voids; modeling; simulation

1. INTRODUCTION

The desire to combine several dice into a single molded IC (integrate circuit) package to get multiple desired functions has led to the development of multiple dice or stacked dice configuration of semiconductor package. Instead of separately mounting electronic components like analog ICs and digital ICs to the PCB (printed circuit board), they can now be integrated into a single package.

For this study, the internal construction of the package or device (Device Z) must be designed to stack smaller Die1 at the bottom and larger Die2 on top, as illustrated in Fig. 1 and Fig. 2. An interposer silicon die was added to support the top die overhang in Fig. 2. The stacked dice were supported by 0.13mm substrate and molded with 0.42mm mold cap.

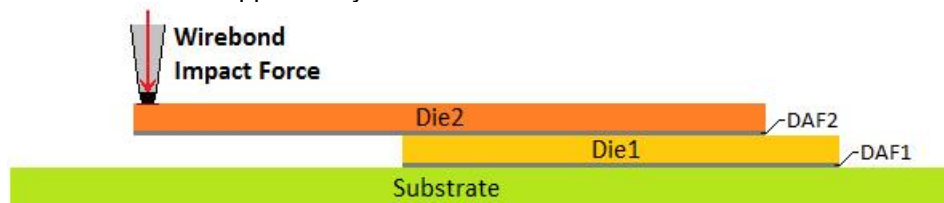


Fig. 1. Cross-section of unbalanced stacked dice, affecting wirebonding process

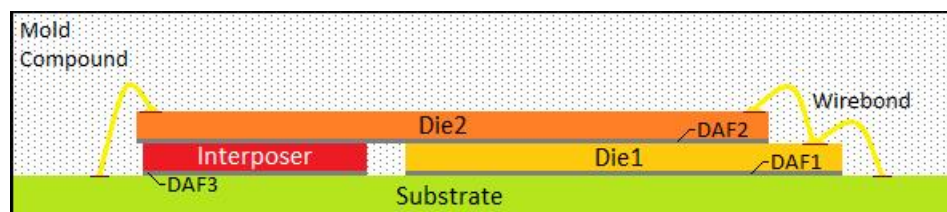


Fig. 2. Package cross-section with added interposer to support Die2 overhang

Actual evaluation of the first version of Device Z, however, showed that there were issues of delamination between top and bottom dice, and die attach voids between bottom die and substrate. In order to resolve the issues encountered, factors involved in the delamination and voids were investigated and package design optimization focusing on substrate was carried out.

2. REVIEW OF RELATED LITERATURE

2.1 Stacked Dice using DAF on Substrates

Stacked dice robust die attach material is the Die Attach Film (DAF). Currently DAF has been widely applied on various high density packages such as BGA (ball grid array), CSP (chip-scale package), SIP (system-in-package), POP (package on package) and so on due to its bleedless and consistent bond line thickness (BLT) [1]. Typical assembly flow of BGAs includes dicing die attach film (DDAF), which integrates the die attach film and the dicing tape [2] [3]. Traditional assembly flow with liquid-type die-attach material can be easily applied onto packaging with DAF. Process could be simplified by eliminating the dispensing and also skipping the post die attach cure. However, DAF void always is one of the major concerns, especially for its application between die and the substrate [3]. Reliability issue of delamination likely occurs at the DAF-substrate interface. DAF void characteristics and its formation and reduction mechanism were then studied. Aside from die attach or diebonding parameters, many other factors are inevitable with regards to the void performance. For Device Z, DAF voids between bottom dice (Die1 and interposer) and substrate were also considered as one of the contributors for the top die (Die2) delamination issue.

2.2 Substrate Package Design Layout

Substrate is normally constructed with metal planes to ensure Cu balance and solder mask balance between layers to ensure no substrate delamination when subjected to reflow [4]. Electrical simulations in relation to the metal plane or metal strips in substrate should govern for resistance, inductance and capacitance. Fig. 3 shows the 2 layer (top side – M1 and bottom side - M2) construction of the substrate for Device Z, with metal balance of 16%.

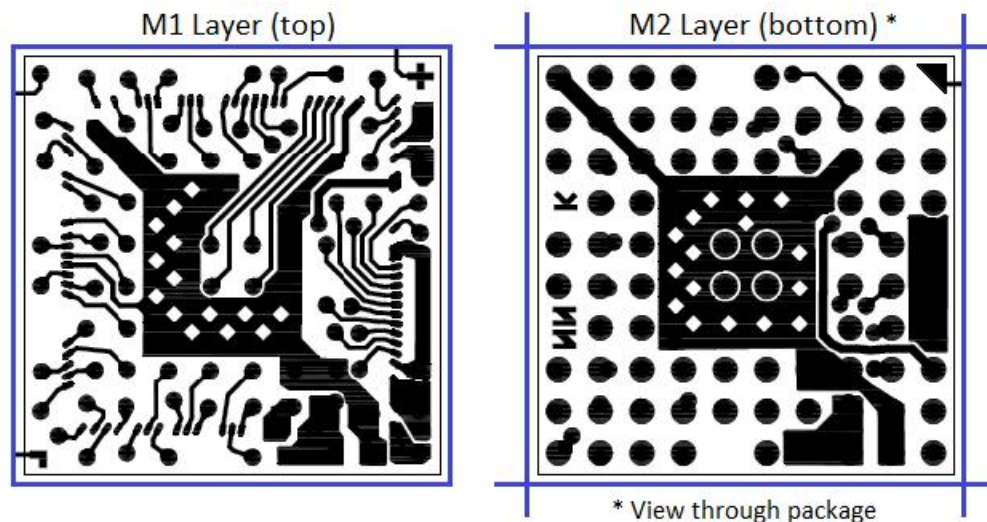
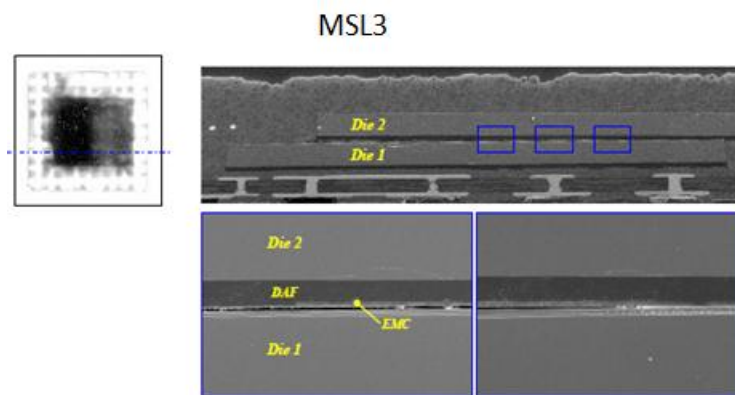


Fig. 3. Substrate design layout top and bottom view

3. METHODOLOGY

3.1 Design Modification and Modeling

The first version of the Device Z design created was using rigid and thin DAF (20um) for all stacked dice to ensure planarity in-between interfaces – 2 bottom dice to substrate and top die to the 2 bottom dice, and to ensure there is enough clearance for the wirebond looping after mold. Back-end assembly of Device Z was performed (from die preparation to package singulation) and submitted samples for Moisture Sensitivity Level 3 (MSL3) to check for delamination. Reliability test showed top die delaminated from bottom dice and observed presence of DAF voids after cross-section validation. Fig. 4-5 shows the MSL3 results.



Cross-section photo of SN1 shows total gap between DAF (of Die2) and Die1 interface. Mold compound (EMC) is evident between this gap.

Fig. 4. Delamination at Die2 (top die)

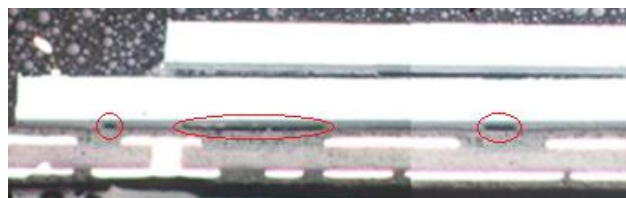


Fig. 5. DAF voids at Die1 (bottom die)

With the results, a fault-tree analysis in Fig. 6 was then performed to prove the phenomenon that the ground plane expands after heat is applied.



Fig. 6. Fault-tree analysis

3.2 Correlation Between DAF Voids and Substrate Topology

With the occurrence of voids between substrate and DAF interface with fixed pattern, affecting top die (Die2) to delaminate, the substrate topography is mostly suspected. Fig. 7 shows that to identify the correlation between void and substrate surface, the cross section was further analyzed and found out that the metal plane expansion serves as fulcrum (not only as source of voids) thus affecting the planarity of 2 bottom dice which resulted to top die aggravated delamination. Therefore, the ground metal plane serves as peaks and solder mask as valleys.

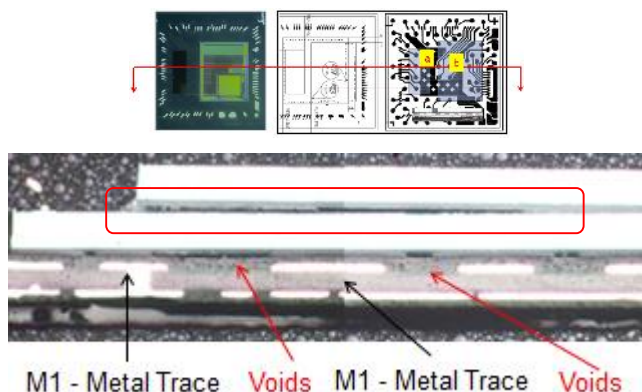


Fig. 7. Metal trace of ground plane served as fulcrum and induced voids, thus top die delamination encountered

It can be observed that in every after metal plane, there is large void between die and substrate. Measurements of the peaks and valley were more than 10um, the thickness of DAF is 20um in this work, namely DAF need fill the gap with depth equivalent with 50% of its thickness, which produces the challenge toward DAF gap filling capability. Therefore, these voids result from the insufficient gap and it can be explained that DAF voids have the properties of fixed position and similar pattern, which is matched with substrate surface topography.

A comparison of non-planarized and planarized substrate was performed to check the difference as shown in Fig. 8. Difference of more than 5 microns observed.

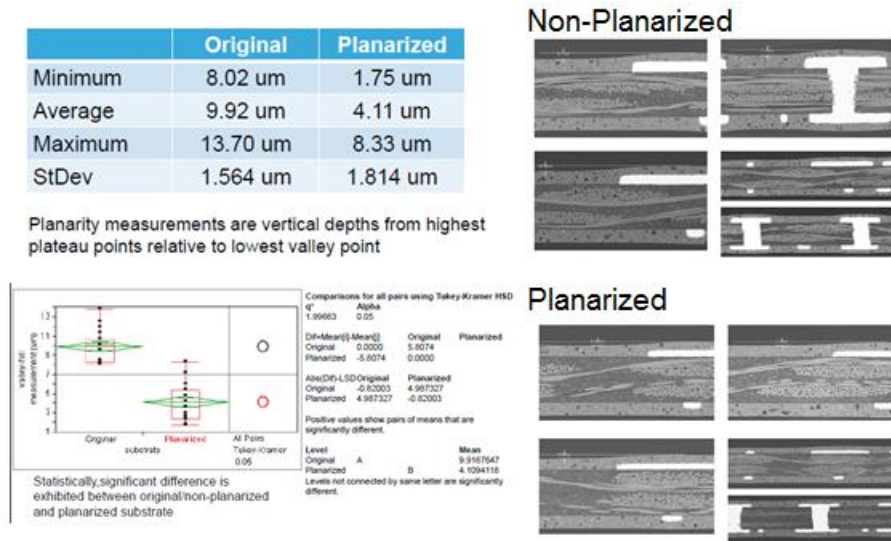


Fig. 8. Non-Planarized vs. Planarized comparison

3.3 Design Iterations

Considering the above findings from fault-tree analysis up to cross-section verification, the root cause of die top delamination and voids between bottom dice and substrate is the substrate topography. Softer and thicker DAF for top die (Die2) was considered to compensate variation of level of the two bottom dice (Die1 and interposer). Table 1 was considered to further validate the hypothesis using the existing materials in the production line.

Table 1. Process evaluation matrix

Leg #	DAF Evaluation	Substrate (with variation)	Remarks
1	Top die and Bottom dice – rigid and thin (20um)	Non-planarized – existing for Device Z	Control Leg, Samples should fail MSL3 to validate the issue (with cross section validation)
2	Top die – softer and Thicker DAF (30um), Bottom dice – rigid and thin (20um)	Non-planarized – existing for Device Z	Samples must pass MSL3 with cross section validation
3	Top die – softer and	Planarized from	Response in time (0) with

Thicker DAF (30um),
Bottom dice – rigid and
thin (20um)

other package

cross-section validation

4. DISCUSSION OF RESULTS

Results based on package thermo-mechanical modeling in Fig. 9 showed that warpage is relatively low. Actual package observation also confirmed the predicted low package warpage. Interface stress due to CTE mismatch is also low which implies that delamination could be due to other factors. Result of the modeling showed low risk if DAF material adhesion is high.

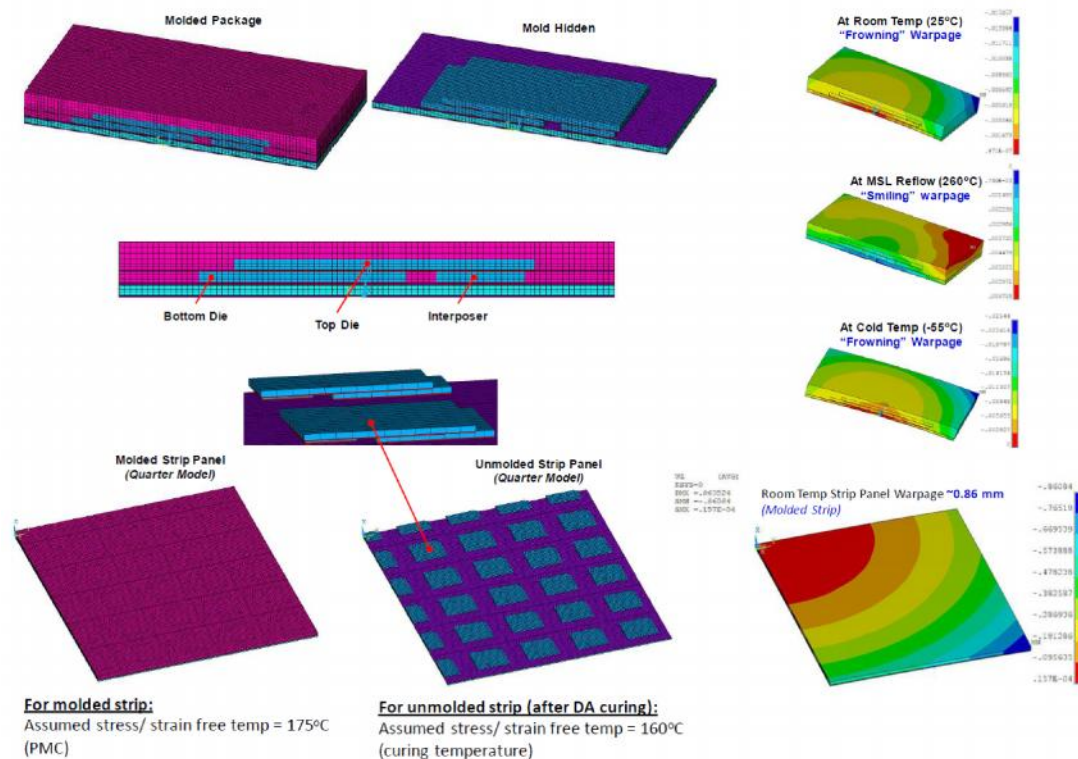


Fig. 9. Device Z thermo-mechanical simulations - package level and strip level

Reliability tests (MSL3) were done using a different DAF, this time softer and thicker DAF for top die (Die2). Shown in Fig. 10 and 11 are the MSL3 results.

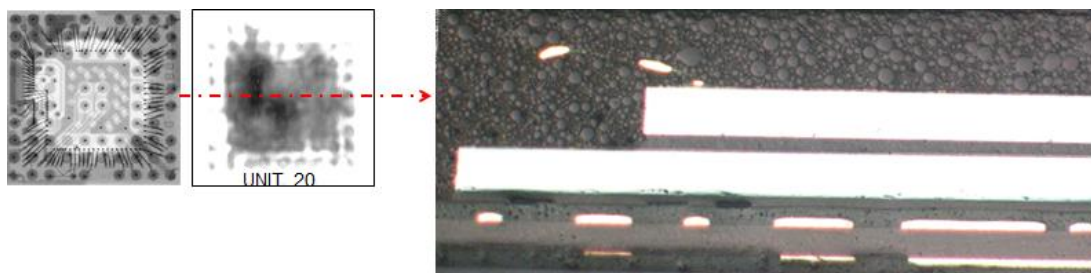


Fig. 10. MSL3 passed on assembly package performed using softer and thicker DAF for Die2 (top die)

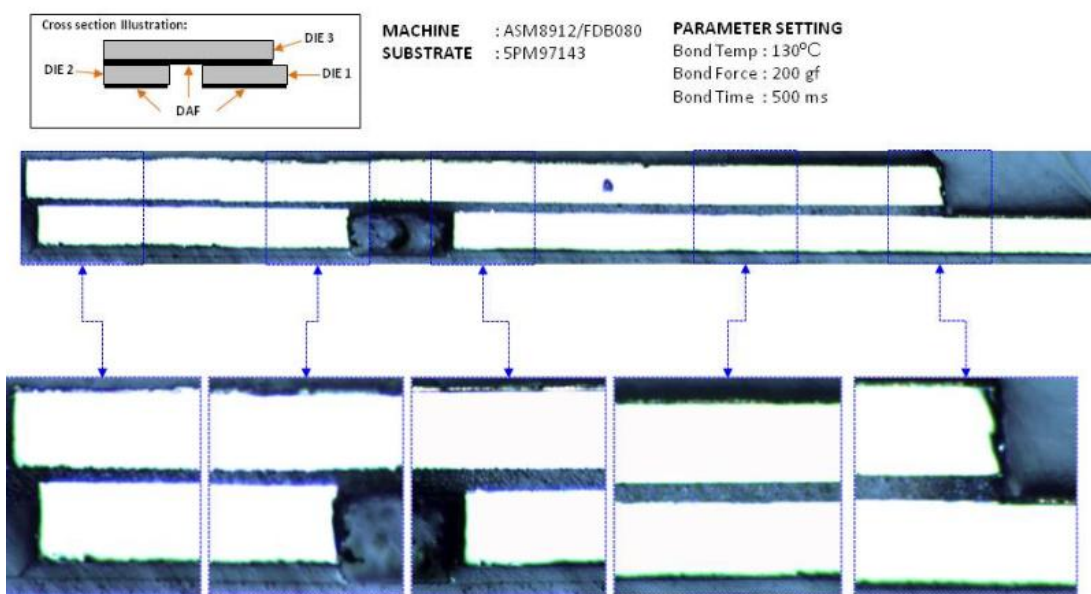


Fig. 11. Die attach stacked die using same rigid and thin DAF showed zero (0) voids for bottom dice at time zero (0)

Results of the evaluation are summarized in Table 2. Based on the results, top die (Die2) should use softer and thicker DAF while bottom dice (Die1 and interposer) should use rigid and thinner DAF on a planarized substrate.

Table 2. Summary of evaluation results

Leg #	Results	Remarks
1	Fail	Previous issue replicated
2	Pass	Passed MSL3
3	Pass	Passed die attach responses

5. CONCLUSIONS AND RECOMMENDATIONS

Based on this study, with the three evaluations done, planarized substrate should be considered for DAF application. Top die (Die2) should use softer and thicker DAF to compensate variation of bottom dice, while bottom dice (Die1 and interposer) should use rigid and thinner DAF to maintain level.

New substrate design for Device Z proposal is shown in Fig. 12, replacing the metal plane in M1 with strip type metals and reducing M2 density resulted to better Cu (copper) balance [5]. Fig. 13-15 showed no significant difference in package electrical modeling performance for resistance, self-inductance and self-capacitance.

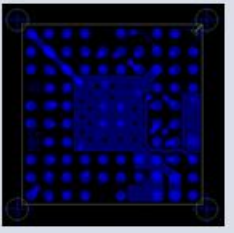
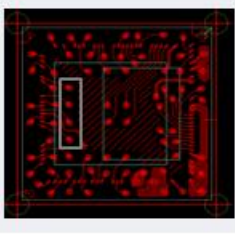
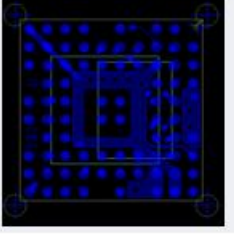
2-Layer, 0.13mm	M1: Top Layer	M2: Bottom Layer	Cu Balance
Non-Planarized (Original design)			16%
Planarized (New design, Cu metal plane changed to metal strips)			6% (better)

Fig. 12. Proposed planarized substrate – metal strip design

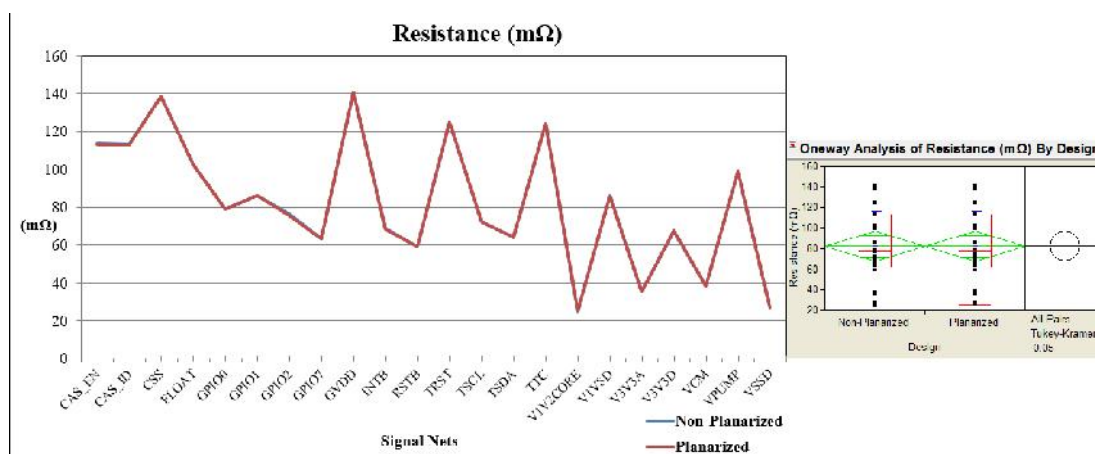


Fig. 13. Resistance comparison of signal nets of 2 designs

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