A SYSTEMATIC APPROACH IN OPTIMIZING STRIP WARPAGE OF AN ULTRA THIN QUAD FLAD NO-LEAD (QFN) PACKAGE

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ABSTRACT

Ultra-Thin Quad Flat No-lead (uTQFN) package has been a very popular IC package for quite some time now. It is usually manufactured using lead frame as a carrier in strip format. However, strip warpage after the molding process is an issue that affects package reliability and the succeeding processes like package singulation. Strip warpage happens due to the CTE (coefficient of thermal expansion) mismatch of the different materials that the package is composed of.

This paper presents a systematic approach used to optimize package strip warpage of an ultra-thin QFN package. The package considered in this study has a 0.55mm thickness and excessive warpage was encountered that already caused problems at succeeding stations, i.e laser marking, mounting and package sawing. Virtual prototyping or finite element modeling, process and statistical techniques were used to understand the warpage mechanism and resolve the warpage-related issues.

1.0 INTRODUCTION

IC package strip warpage is inherent in any molded package due to CTE (coefficient of thermal expansion) mismatch of the different materials in the package. But this would start to become an issue when it is already excessive and causes package reliability and processing problems. That is why there is usually a defined specification for warpage in package assembly manufacturing.

During the introduction of a new QFN product at ST-Calamba, an excessive strip warpage was causing issues on succeeding stations but concentration would be those of package sawing problems. The package is quite thin (~0.55mm total package height) and the schematic is illustrated in Figure 1. The encountered warpage was in a "frowning" mode as shown in Figure 2. So a systematic approach to reduce the excessive warpage would be discussed.

Figure 1. Schematic of the ultra-thin QFN package in which excessive strip warpage was encountered.

Figure 2. Ultra-thin QFN package molded array strip with "frowning" warpage at live bug position.

2.0 REVIEW OF RELATED LITERATURE

2.1 Molded Array Strip Warpage

IC packages, either lead frame or substrate-based, are usually molded in a strip format. Due to the large matrix of molded strip of these packages, the excessive warpage and over stress by thermal mismatch of different materials of package occur during manufacturing process. There are several factors that affect warpage, but underlying package geometries and molding compound properties are top among the causes. While a set of molding compound properties may produce very little warpage in one array package, they may generate completely unacceptable warpage in another due to the variations in package geometries. In order to ensure the minimum warpage in these types of array packages, regardless of varying geometries, molding compound properties have to be adjusted and customized for each package.[1]

However, there are cases where the package design is already fixed as well as the materials used like molding compound. So process optimization has to be done in order to reduce warpage without changing anything on the design or the package materials. The use of weights placed on top of a stack of molded lead frame strips during post mold cure

(PMC) is one of the process techniques being used. Another related study[2] has optimized the cure process where they found out that slow cooling is much helpful in warpage control. Decreased cooling rate (slow cooling in oven) would give enough time for stress absorption and release, and thus is a critical solution for warpage reduction.

2.2 Issues Related to Warpage

With excessive strip warpage, issues ranging from difficulty in processing the strips to package problems like package crack could happen.

Package Crack: Any evidence of crack on the package body visible under the unaided eyes is rejectable. Figure 3 illustrates a molded strip with package induced because of high warpage.

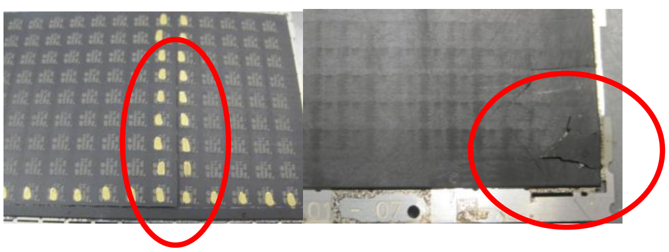


Figure 3. Molded strip showing package crack.

Microcrack: Any evidence of crack on the package body is rejectable. Related example is shown in Figure 4.

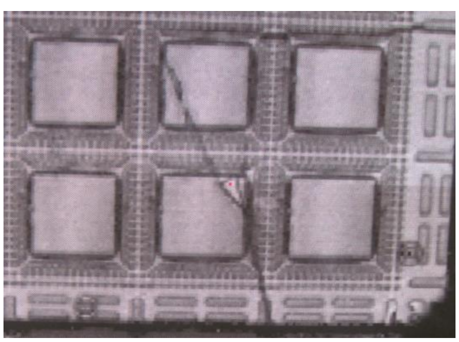


Figure 4. Strip with micro-crack.

Misaligned Cut/ Package Offset: Reject for any offset measurement greater than 0.05mm/2mils (Figure 5). This is another problem that could be encountered if there is excessive strip warpage.

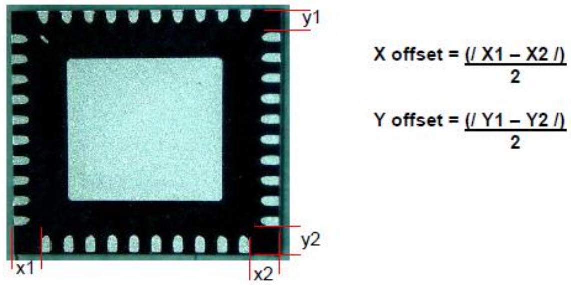


Figure 5. Illustration of how package offset is calculated.

3.0 EXPERIMENTAL SECTION

3.1 Strip Panel Warpage Modeling

The uTQFN package strip panel was modeled using finite element method. This was done to understand the warpage mechanism for this ultra-thin package and explore ways to reduce warpage. Figure 6 shows the 3-D finite element model of the molded package strip panel.

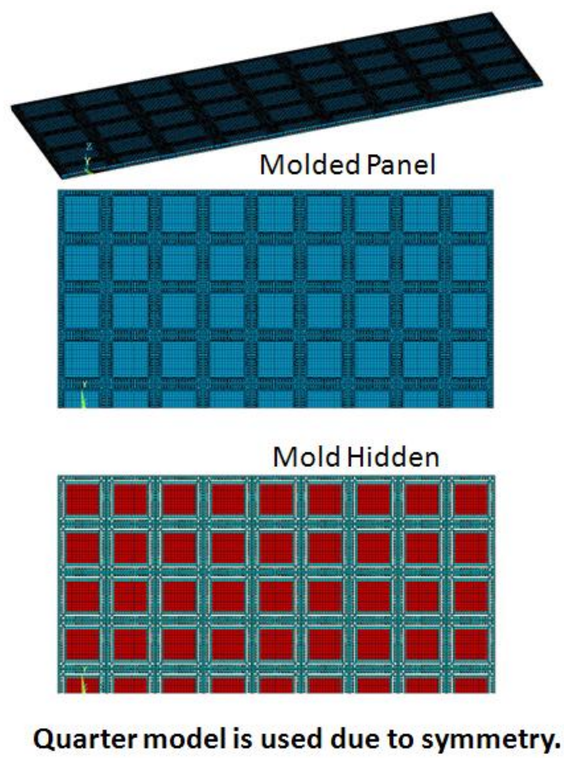


Figure 6. Strip panel finite element model.

The existing package was modeled and then two options were also assessed for improvement on strip warpage. As illustrated in Figure 7, the other two options are having thinner lead frame. Option 1 has a total package height of 0.475mm and Option 2 has 0.55mm, which is the same as the total package height of the existing package.

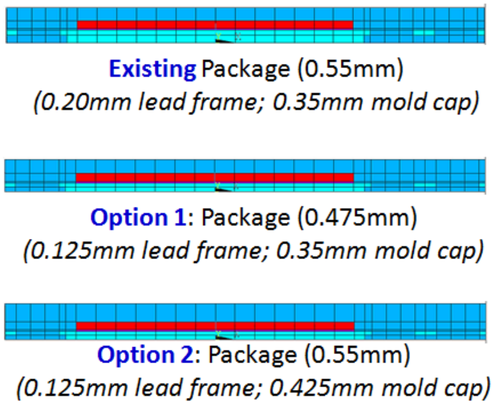


Figure 7. Options modeled to improve warpage performance.

3.2 Actual Evaluation and Process Optimization

Per process mapping of strip warpage was performed by measuring warpage per process station from Mold to Chemical Deflash. This is to determine the most significant contributor of package warpage for uTQFN package. The conditions used are standard PMC and Deflash condition for uTQFN package as listed in Table 1.

Table 1. Standard PMC (Post Mold Cure) and Chemical Deflash Conditions

PMC Condition

Machine	Hanseo Oven
Temperature	175°C
Time	4 hrs
Weights	6 kg

Chemical Deflash Condition

Chemical Bath Temp	95°C
Immersion Time	30 minutes

Using SmartScope CMM (coordinate measuring machine), several points were taken per panel. The measurement points taken are illustrated in Figure 8. Then, the measured data were subjected to Statistica software to generate the warpage profile.

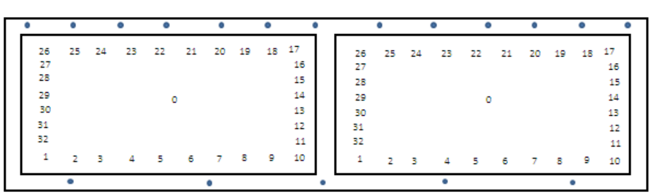


Figure 8. Warpage measurement points.

Different weights were also placed on top of the strip during PMC to determine the effect of weights on strip warpage. And some strips were placed in a "live bug" position and others in "dead bug" position to study the effect of strip loading position or orientation on strip warpage.

4.0 RESULTS AND DISCUSSION

Finite element modeling shows that strip panel warpage is in "frowning" mode (Figure 9). This is due to the higher CTE of the lead frame material as compared to the molding compound and silicon die. During cool down from PMC temperature (~175°C), the lead strip contracts faster and tries to pull the strip and results in "frowning" warpage. This warpage also agrees well with the actual uTQFN strip warpage.

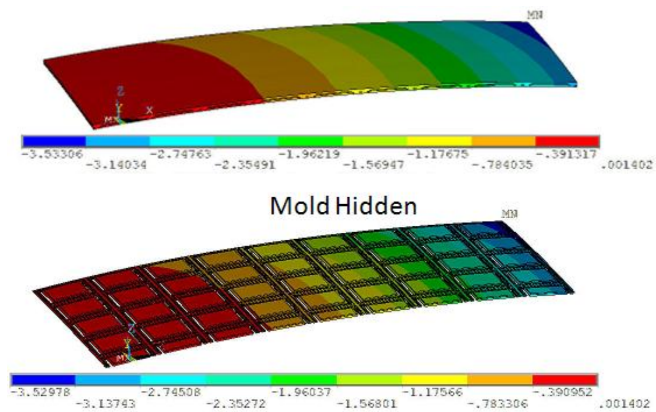


Figure 9. Strip panel warpage result in "frowning" mode after PMC (post mold cure).

Warpage results for the different options considered are summarized in Figure 10. It shows that increasing the mold encapsulation thickness and reducing lead frame thickness would effectively reduce the strip warpage.

Since the existing package shows a "frowning" mode, increasing the amount of molding compound (i.e. increased mold cap) would allow the molding compound to increase its influence and pull the strip into the opposite direction and thus reducing warpage.

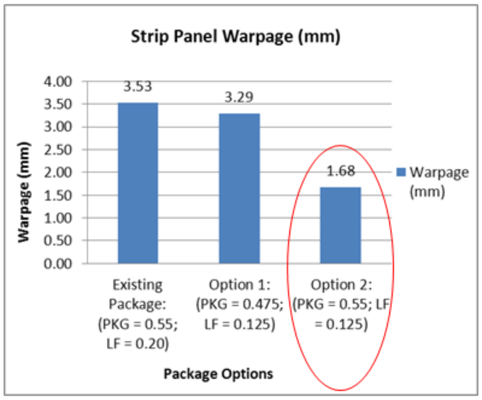


Figure 10. Strip panel warpage results comparison for the different options.

Actual warpage evaluation after mold shows the following results in Figure 11. Figure 12 shows the strip warpage after PMC and Figure 13 for the warpage after Chemical Deflash and Waterjet.

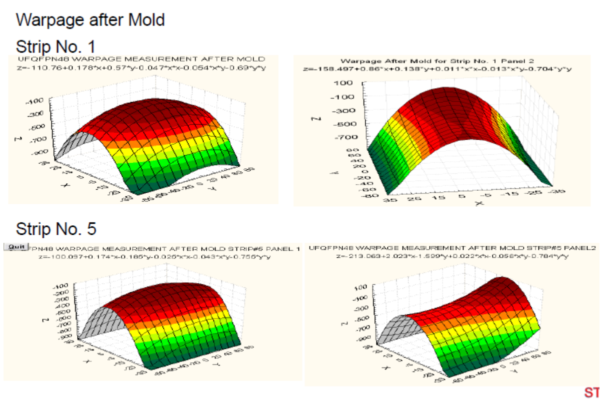


Figure 11. Strip panel warpage after mold.

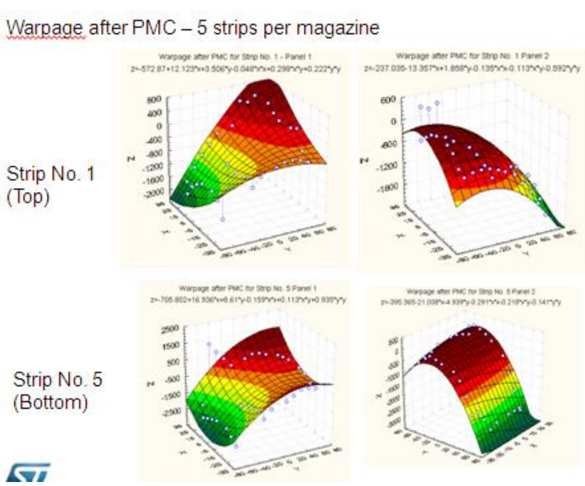


Figure 12. Strip panel warpage after PMC.

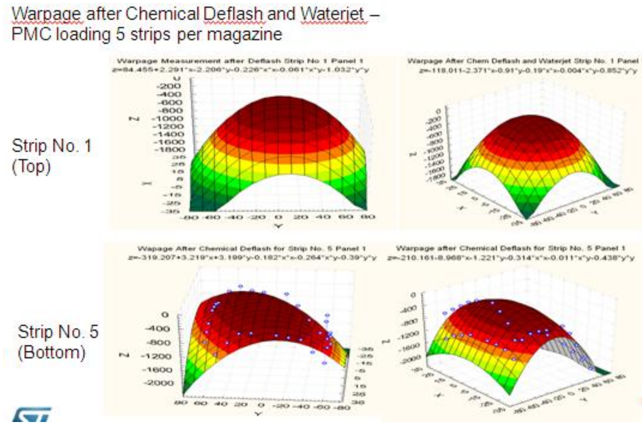
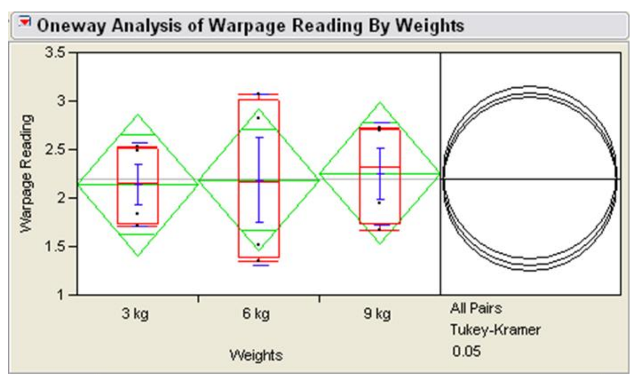


Figure 13. Strip panel warpage after Chemical Deflash and Waterjet.

Based on the evaluation results, it was found out that Chemical Deflash at a chemical bath temperature of 95°C did not contribute to further strip warpage. Warpage after PMC was almost maintained maybe due to the fact that the epoxy molding compound was already fully cured and temperature at Chemical Deflash is already significantly lower than PMC temperature or 175°C.

Regarding the effect of weights, ANOVA (Analysis of Variance) in Figure 14 showed that there is no significant difference in strip warpage for the different weights used: 3kg, 6kg and 9kg. It means that 3kg placed on top is already enough to maintain the strip in a flat orientation during PMC and increasing the weights does not provide further warpage improvement.

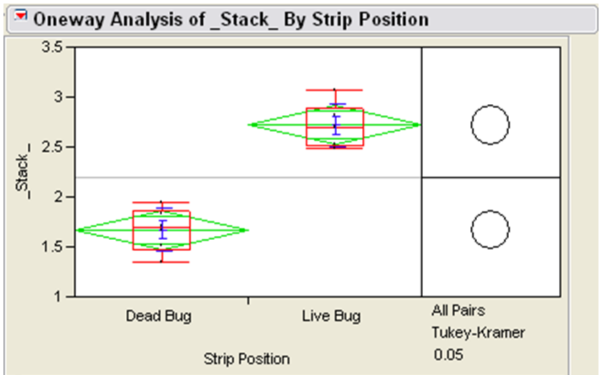


Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Weights	2	0.0286022	0.014301	0.0345	0.9662
Error	9	3.7290087	0.414334		
C. Total	11	3.7576109			

Figure 14. Analysis of Variance (ANOVA) of warpage by weights.

However, results shown in Figure 15 indicate that there is significant difference in strip warpage for the two different strip loading positions during PMC. The "dead bug" strip loading position provides better warpage performance (lower warpage). Table 2 summarizes the warpage results for the different weights and strip loading position.



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Strip Position	1	3.2896741	3.28967	71.2512	<.0001
Error	10	0.4617008	0.04617		
C. Total	11	3.7513749			

Figure 15. Analysis of Variance (ANOVA) of warpage by strip loading position or orientation .

Table 2. Warpage Evaluation (Effect of Weights and Loading Position)

Evaluation Run	Weights	Strip No.	PMC Loading Orientation	Average Warpage Measurement	
				Panel 1	Panel 2
1	3 kg	1	dead bug	1.71	1.83
		2	live bug	2.48	2.53
2	6 kg	3	dead bug	1.35	1.507
		4	live bug	2.82	3.07
2	9 kg	5	dead bug	1.67	1.95
		6	live bug	2.6917	2.716

Note: Additional 1 3kg weight was added during cool down)

5.0 CONCLUSION

This study has shown that a systematic approach that includes finite element modeling, statistical and process optimization techniques would be able to effectively address strip warpage issues in thin QFN packages.

Virtual prototyping or finite element modeling could provide better understanding of the strip warpage mechanism and be used to explore options to reduce warpage.

6.0 RECOMMENDATIONS

It is recommended to use a systematic approach in optimizing package strip warpage. And finite element modeling should be used early on in the package design process to come up with an optimized package in terms of warpage such that the lowest warpage is attained through combined design and process optimization.

7.0 ACKNOWLEDGMENT

The authors would like to extend their sincerest appreciation to the following: Willy Cabreros, Jun Bernabe, Addonyz Antonio and the rest of ST-Calamba Assembly and CPA/NPI team members. Thanks also to Jeff Talledo for helping in the package strip modeling and simulation.

8.0 REFERENCES

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9.0 ABOUT THE AUTHORS

Arnold Rada received his B.S degree in Mechanical Engineering from Adamson University. In November 1999, he joined Philips Semiconductor Philippines Inc. wherein he spent his 7-years of service as Mold Process Engineer for Standard and Advance package product. In the year 2006, he was transferred to NPI Engineering to handle qualification of new materials as well as New Products introduced to assembly manufacturing. In the year 2010, he was involved in the start-up of the Scalpack package where his major activity focuses on Initial production management, that scope of which is to handle preparation of the line in terms of manpower, material, documentation/methods, process improvement and quality related issue.

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