Original Research Article

Validation of New Substrate Design for the Improvement of Strip Warpage on LGA packages

ABSTRACT

Substrate warpage have been affecting production performance on semiconductor manufacturing. The unacceptable response results to loss of productivity losses and yield detraction. Different process improvements have been experimented to contain the problem, but results are not maintained and found to be not robust. This is where design innovation plays the part. Solder mask opening on the base material of the substrate is considered to have a favorable response after subjecting it to different environment conditions. From fast indexing and machine movement up to high thermal application on oven curing, having a robust solder mask design makes the unit acceptable and with quality. This manuscript will be discussing how the solder mask of the substrate is optimized to achieved minimal or zero substrate warpage.

Keywords: Substrate Design, Solder Mask Opening, MEMS, Warpage, Front-of-Line, Land Grid Array

1. INTRODUCTION

In the fast-pacing technology and innovation all around the globe, every industry strives for limitless and continuous improvement. Companies with manufacturing plants, services and labor demands on the open market are seizing all opportunities for a better product that customers expect on them. Semiconductor industry is one of the leading examples who projects modern technology and miniaturization on their products. From enormous size of integrated circuits or ICs to nano size processors that can be found on advanced gadgets we use every single day of our lives. Every individual is committed to achieve satisfaction and quality of their products and services

On the semiconductor package of LGA's or Land Grid array for micro electromechanical system products, substrate warpage is one of the challenges the manufacturing faces and experience. Substrate warpage as seen on Fig. 1 is the reaction of the material to "bend" or warp after subjecting to oven curing process.

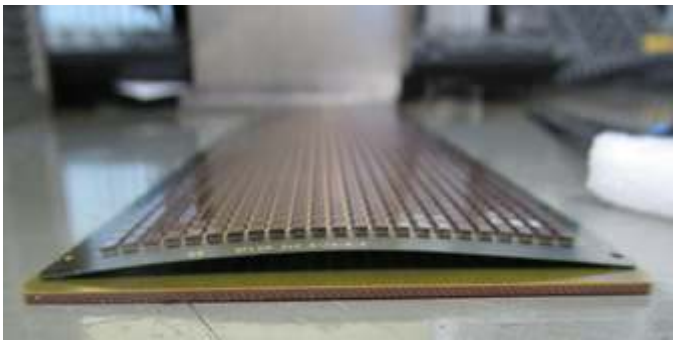

Fig. 1. Warpage visible on substrate after oven curing

High warpage that is already evident after oven curing as shown on Figure 1 is no longer acceptable on the succeeding process step of wire bonding. The warpage measurement acceptance is 1.2mm altitude from the flat surface but the measurement after oven curing is found to be 4.0mm. At time zero, the strip warpage measurement is already at 2.4mm and is already out of acceptance criteria. The authors have found an opportunity to study the problem and explore solutions that can be offered related on the substrate revisions.

2. REVIEW OF RELATED LITERATURE

Substrate warpage is one manufacturing issues that were unexpectedly encountered by manufacturing engineers. There are several factors that affect this substrate warpage. Temperature during oven curing of products is one of factors considered. Several evaluations to use different cuing profile were performed and based on specific material affected, best curing profile was defined. as seen on Fig. 2. sample of design of experiments on different temperature profile that contributes to substrate warpage, and its effect.

Run #	Oven Cure Profile	Remarks
Run 3		Cool Down to 130degC with 20 minutes dwell time. Total cool down 60 minutes.
Run 4		Cool Down to 120degC with 20 minutes dwell time. Total cool down 60 minutes.
Run 5		Cool Down to 110degC with 20 minutes dwell time. Total cool down 60 minutes.

Fig. 2. Design of experiment of different oven curing profile

Other studies performed process improvements by applying weights on the material during heat application. Weights will control the movement of substrate by applying opposing force

on the direction of the warpage. This practice has been used by manufacturing ages ago, and not all results were favorable. That is why the design improvement and modification of core materials is put into play to have robust resolution.

3. METHODOLOGY

Supported by various research and the related literatures on this study, the authors first aim to measure warpage from time zero and see how the measurement behaves as the process progresses at front-of-line (FOL). Shown on Figure 3. is the FOL Process flow where the authors will verify the warpage measurement step-by-step.

Fig. 3. Design of experiment of different oven curing profile

Once strip behavior is comprehended, the authors have considered to validate distinctive designs of solder mask opening (SMO) as consulted and recommended from the supplier. Validation includes the parallel run of the existing SMO design versus the modern designs recommended by the supplier as the SMO design affects the warpage measurement.
Upon result availability, the authors would conclude the best design to demonstrate low warpage measurement.

4. RESULTS AND DISCUSSIONS

4.1 Measurement of Strip Warpage for Every FOL Process Steps

Existing design of substrates has its SMO around each of every unit in the strip. Shown on Figure 4 is the reference substrate design illustration and the warpage condition at Time Zero (T0). At T0, warpage measurement is found with average of 1.6mm.

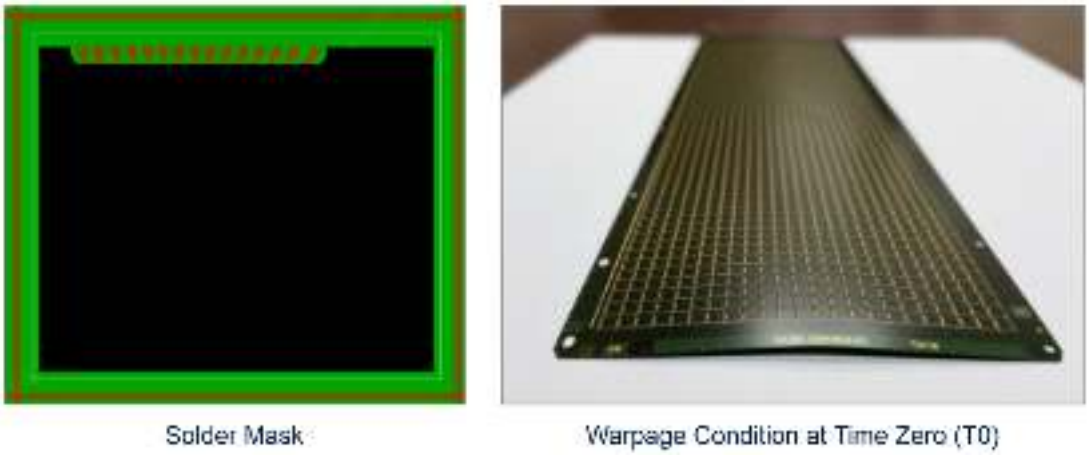

Fig. 4. Existing Substrate Design and Warpage Condition

Upon process application, the warpage measurement increases when applied with heat along the processes. Curing and cooling of the strip helps the strip to be flattened but not enough to reach 1.2mm acceptance warpage altitude. Shown on Figure 5. is the behavior of the strip warpage along the process. Three strips were used to validate the warpage results of the existing design of the strip.

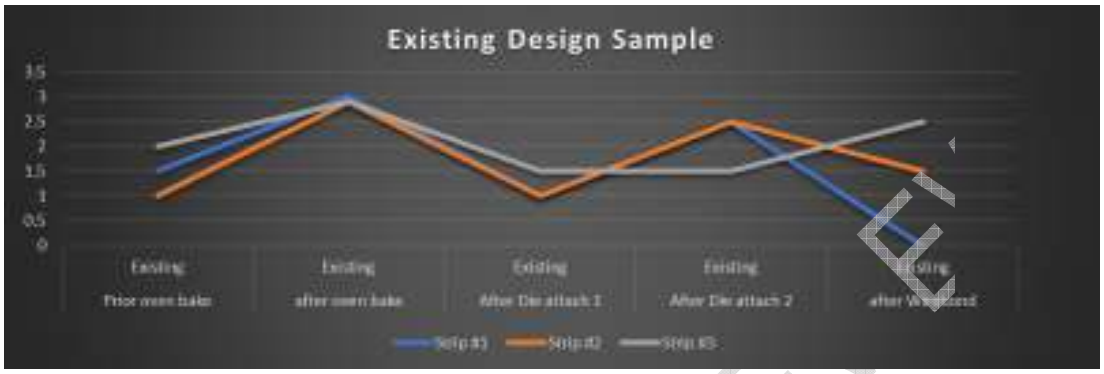

Fig. 5. Existing Design Warpage Measurement per Process Step

With the behavior observed on the existing strip, the authors have proceeded to assess the recommended innovative designs of substrates aiming to reduce the warpage to avoid issues on the next process steps at FOL.

4.2 Identification of the New Designs of Substrates

Upon validation of the behavior of existing substrate, two recommendations were given by the supplier and was considered for evaluation. One modification called as the Scheme 1 pertains to the whole strip where the SMO design is changed on the bottom strip rail, aiming to control the whole warping of the strip. Another modification called as the Scheme 2 pertains to the SMO design changed per unit where gold plated bars were covered by SMO on the long side of the strip. Both designs are shown on Figure 6.

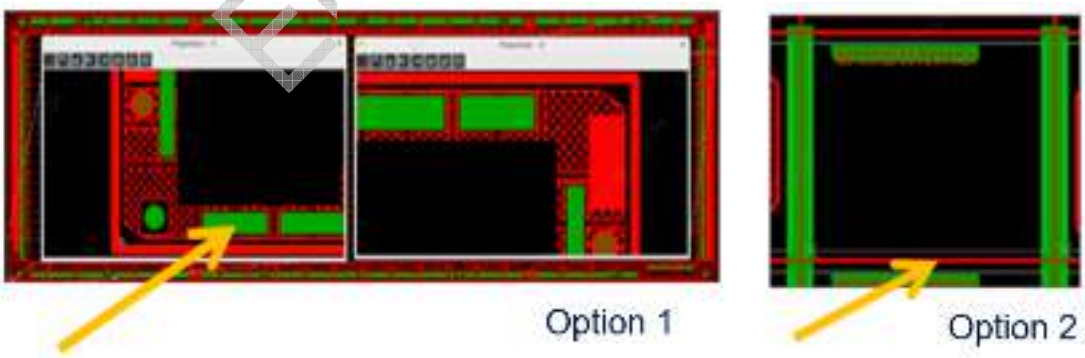

Fig. 6. New Substrate Designs

Simulation of both designs at supplier side shows that Option 1 cannot be longer considered as it has no improvement from the existing design. On the other hand, Option 2 proceeded into validation on the assembly line as progress is evident on the simulated results from the supplier. Shown on Figure 7 is the process probability measure for both designs shown that

Option 1 is not recommended for further validation and Option 2 can proceed with further analysis.

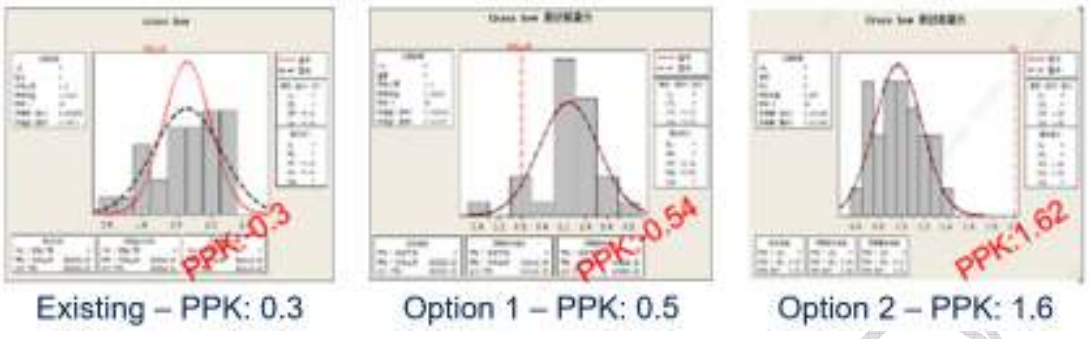

Fig. 7. Process Performance Between Existing and New Substrate Designs

With the data on hand, the authors concurred to continue the validation run of the substrate design from Option 2. Parallel run for existing and considered new design will be verified.

4.3 Validation Run Between Existing and New Substrate Designs

Then new design of substrate from Option 2 is used for validation at FOL. Warpage was measured at every process step as gathered on the existing design. Figure 8 shows that the warpage of the strips has different and improved response where maximum warpage measured is only 1.0mm. Statistical study shown on Figure 9 indicates that there is a significant difference on the performance between the existing and the new substrate designs showing that the new substrate design has the lower and favorable results in terms of warpage measurement.

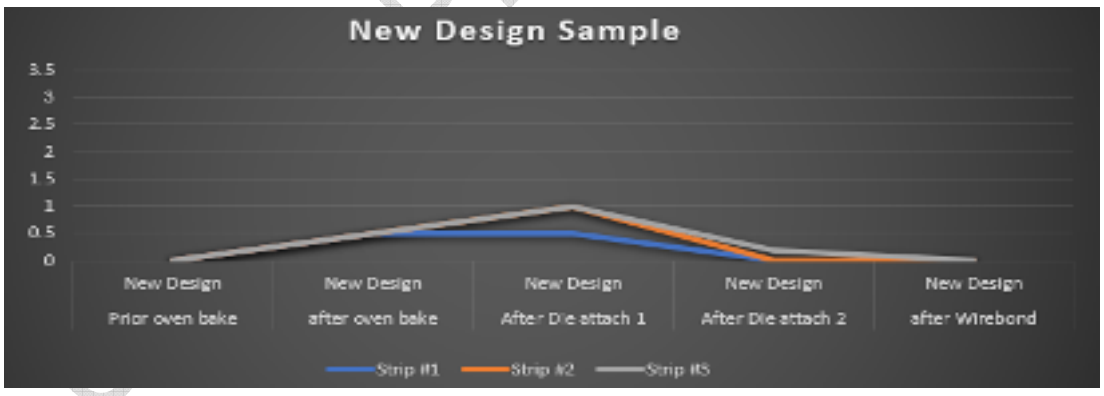

Fig. 8. New Design Warpage Measurement per Process Step

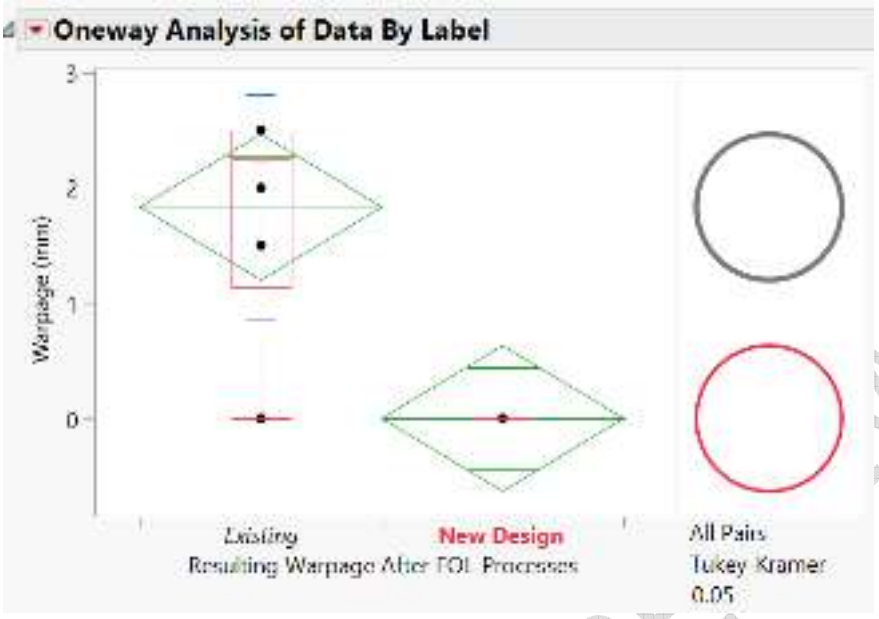

Fig. 9. Statistical Study Results Between

Additional evidence shown that the study and measurement is valid as warpage was evident on sample photos shown on Figures 10 and 11. Figure 10 is the progress of warpage along the process for existing design while Figure 11 shows the progress from new substrate design.

Fig. 10. Existing Substrate Validation Photos

Fig. 11. New Substrate Validation Photos

Data and analysis shown that the validation described on the methodology is suited for the identification of the best design that would demonstrate the substrate design with best warpage measurement demonstrated.

5. CONCLUSION AND RECOMMENDATIONS

Thru the data gathered upon the authors' validation, it has been concluded that the existing substrate design have warpage issues that is related with the SMO. Out of the two new designs recommended by the supplier, it was found out that Option 2 has the most significant result to lower down the warpage at FOL. It was concluded that the design of Option 2 with SMO covering the gold-plated bars at the long side of the strip improves the warpage measurement significantly.

In parallel, the authors recommend on consideration of the Option 2 Design of Substrate to lessen the warpage measurement. It is also recommended the validation made on this study to monitor and understand the warpage behavior to verify the design effectiveness.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

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