# Final Module Yield Improvement by Increasing the Adhesion of SU8 to Microelectronic Devices using a DMAIC approach

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**Abstract:**

**SU8 is a photo definable epoxy used to protect microelectronic devices during the assembly process. The SU8 structures must withstand extreme temperatures and pressures during the over-mold process. A key process measurement that tracks the ability of the SU8 to withstand the assembly process can be monitored by shear adhesion testing. This paper shares the methodology used to discover which process parameters impact over mold failures and the improvement in adhesion which resulted in a final assembly yield improvement.**

## BACKGROUND

Photo-definable epoxies such as SU8 are used for a variety of applications such as WLP (wafer level packaging) which is part of a low-cost packaging solution (Topper, 2010) These low-cost mold-injected packages are desirable but requires the SU8 structures to have very good adhesion during the over-mold process. Any leaching of the over-mold material into the resonators during the over-molding process will result in module yield loss.

New studies using the DMAIC approach (Define, Measure, Analyze, Improve and Control) to understand and eliminate the variation in the adhesion were conducted. This paper presents those activities and improvements and the consequent increase in final module yields.

## INTRODUCTION

TriQuint manufactures devices that are used in a variety of applications. These devices are packaged in a variety of ways including via WLP (wafer level packaging). These packages are desirable but must withstand temperatures greater than 180C, local lid attachment pressures greater than 100g of force, transfer pressures greater than 7.0MPa, post mold cures and high temperature/ short duration reflow temperatures greater than 260C. It is critical that the SU8 walls and lid hold up during this assembly process to prevent yield loss from leaching of the over-mold material into the resonator areas.

Previous studies (Nordstrom, 2005; Campbell, Ivie 2012) have described the processing challenges to ensure good adhesion of the SU8 to the variety of materials used as substrates. Extreme process controls are needed for a variety of parameters including cleanliness of the incoming substrate; average film thickness; uniformity of the coated film; de-hydration bake temperatures, times and methods; post coat bake (PCB) temperatures, times, and methods; exposure dose and method; post exposure bake (PEB) temperatures, times, and methods; develop methods; and final cure temperature, times, and methods. All of these impact adhesion. Further, even when all these parameters are maintained, acceptable shear adhesion can be elusive.

In this study, data was collected to establish a relationship between adhesion and final module assembly yield. This would allow wafers to be culled at the wafer fab level and not at the module build level, a more cost effective solution.

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## METHOD

Fabrication facilities often have a variety of process improvements and process problems to address, prioritizing these multiple possible selections can prove to be daunting. Using a DMAIC approach can aid in the selection of which process(es) or segments of a process to attack.

*Define:*

For this particular project the selection was based on the following indicators and desires:

1. High external indicators (Assembly yield and cost)
2. Internal indicators (Process parameters)
3. The desire to improve the indicators in order to meet ZERO DEFECT quality targets

These indicators were analyzed using several tools Pareto charts, trend charts (Figure 1: Final Module Yield and Figure 2: Shear Data of SU8), box plots, and histograms that helped us to understand the problems and prioritize the issues.

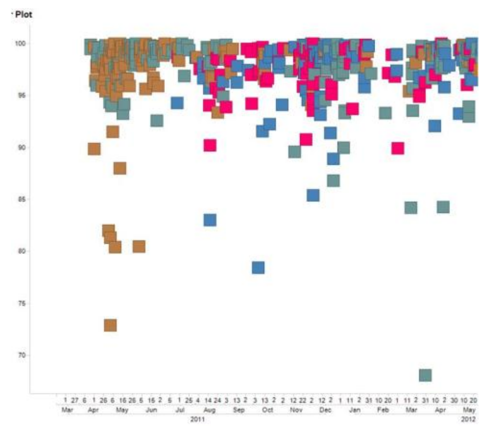

Figure: 1 Final Module Yield

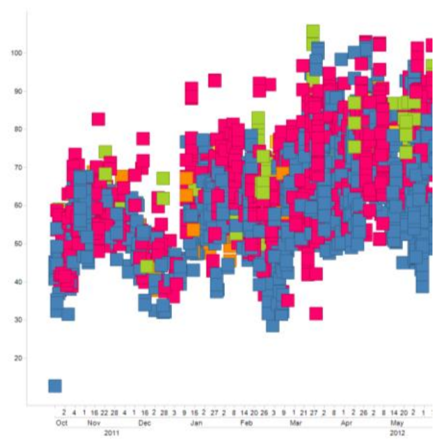

Figure 2: Shear Data of SU8

*Measure:*

It has been assumed that intrusion into the cavities of the SU8 (and final module yield) has a direct relation to SU8 adhesion (as measured by shear values) however, to date there has been no statistical correlation performed. It was attempted to define the relationship by investigating data from many builds and applying a binomial model. However, given the large amount of explanatory variables it took many hours for the algorithm to converge. Even so there was not sufficient confidence in the results. Therefore, it was decided to use Yield loss measured as number of defective units per 100,000. 100,000 was used to get sufficient resolution in yield values.

A Poisson model was used (because of rare events) and the log of defects was determined. This can be seen in Figure 3: Adhesion and Defects

| Avg_Adhesion | LogDefects | Defects |
|---|---|---|
| 36.2 | 2.146 | 140.0 |
| 51.0 | 2.04 | 109.6 |
| 69.5 | 1.95 | 89.1 |
| | | |
| Change | | 50.8 |

Figure 3: Adhesion and Defects

Once the relationship of adhesion and yield loss was determined, root cause analysis could be performed. The team used a cause and effect diagram that was fed with tools such as brainstorming, process maps, affinity diagrams and interrelationship diagraphs. Using a process map it was determined there were many delays in the process which could contribute to the variation in adhesion.

*Analyze:*

Once the few X's were determined, the team started to collect data using collection plans.

Those X's were:

-Delay times between operations
-Surface treatment
-Cross linking of the SU8
-Material

This data was analyzed using 6 sigma and Spot-Fire tools such as correlations and histograms and box plots to verify or discard the causes. In Figure 4: Delay between Develop and Cure, a 48 hour delay results in a 17% decrease in shear strength.


Figure 4: Delay between Develop and Cure

Investigation into the cross linking of the SU8 using the standard cure oven indicated that the SU8 was not fully cross linking, regardless of the temperature and time the SU8 was exposed to. Cross linking is a key indicator of the film SU-8 stability. Cross linking begins at the exposure step where the formation of a strong acid during the exposure process and is followed by acid-initiated, thermally driven epoxy cross-linking during the post exposure bake (PEB) step.

To determine the complete curing of SU8 TGA was used to test the thermal stability. A controlled hard bake (cure) temperature slightly below glass transition phase temperature will fully cross link the material. As can be seen in Figure 5 TGA Data for Process of Record, the SU8 is not fully cured as indicated by residual curing still taking place.

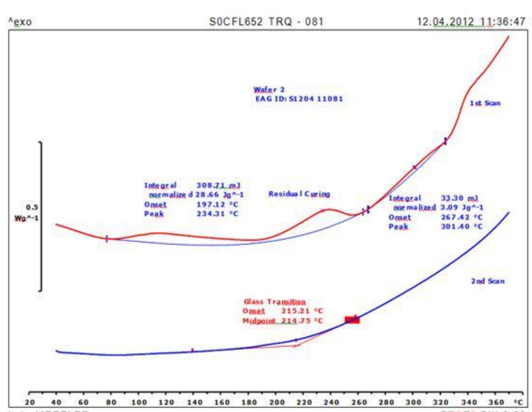


Figure 5: TGA Data for Process of Record

*Improve:*

Having the root causes identified, the next step was to develop as many solutions as possible. Benchmarking, design of experiments, and process mapping were some of the methods used to improve the process. Based on the potential solutions, ICE analysis (Impact, Cost and Ease of Implementation) was used to select the preferred criteria. It was determined that reducing delay time between develop and cure was important, but because of uncontrolled variables such as equipment availability, staffing and wafer start levels that it would not be easy to implement a forced time delay. In addition since exposed and developed SU8 cannot be reworked without impacting device performance, it was decided to instead look at improving SU8 adhesion by better cross-linking the SU8 and doing so earlier on in the process flow.

A design of experiments was used varying methods of curing, and curing times and temperatures as well as placement in process flow. Inserting a hot plate cure after the develop step, as shown in Figure 6: Process Flow, resulted in fully cross linking the SU8 as verified in Figure 7: TGA Data for New Process of Record

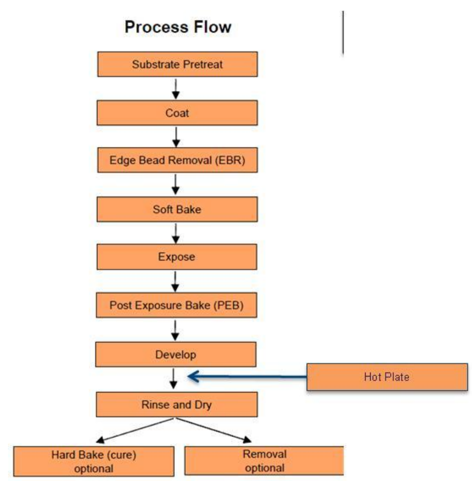


Figure 6: Process Flow

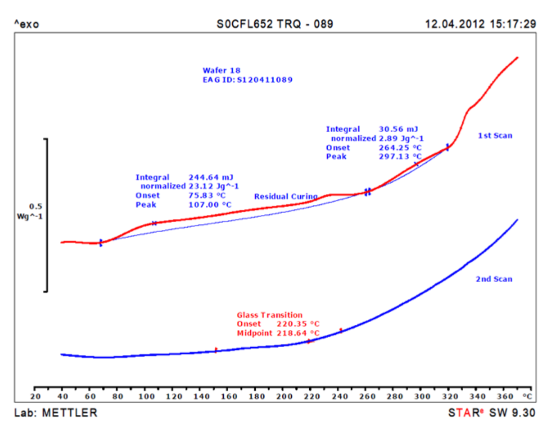


Figure 7:TGA Data for New Process of Record

## RESULTS

*Control*

After testing and implementation of a hot plate cure the shear (adhesion) values not only increased but the variation decreased as well. This is shown in Figure 8 Hot Plate Cure Adhesion.

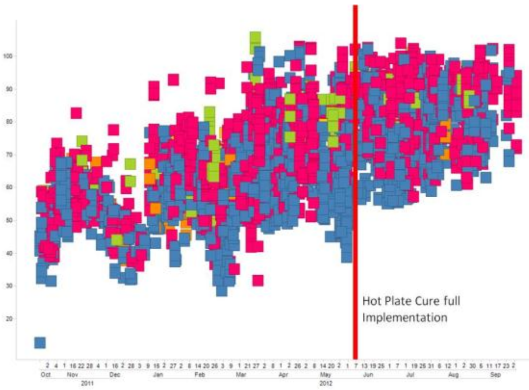


Figure 8: Hot Plate Cure

The most important aspect of this project was final module yield. As shown in Figure 9 Final Module Yield and Hot Plate Cure, the module yield has been stabilized.

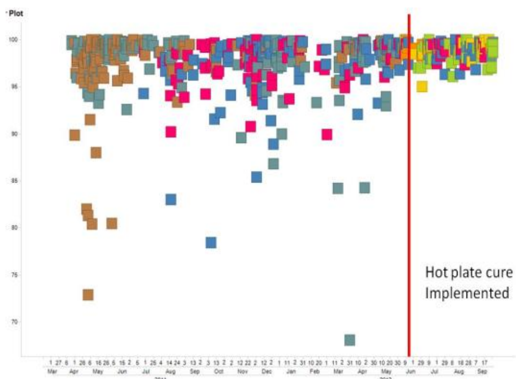


Figure 9: Final Module Yield and Hot Plate Cure

## CONCLUSIONS

Following a DMAIC process the project was defined, measured, root causes analyzed, corrective action implemented and verification of process improvement sustained. Implementing the hot plate cure stabilized the effect on shear (adhesion) data due to process delays between develop and cure while also increasing the adhesion which resulted in a increase in Final Module yield and reduction in yield variation.

## ACKNOLEDGEMENTS

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## ACRONYMS

DMAIC: Define/Measure/Analyze/Improve/ Control method of process improvement.
PCB: Post Coat Bake also known as soft bake
PEB: Post Exposure Bake
SAW: Surface Acoustic Wave device
WLP: Wafer Level Packaging

## References:

[1] M. Topper, T Fischer, T. Baumgartner, H. Reichl. "A Comparison of Thin Polymers for Wafer Level Packaging." Electronic Components and Technology Conference , 2010.

[2] M. Nordstrom, A. Johansson, W. Nogueron, B. Clausen, M Calleja, A Boisen, Investigation of the Bond Strength between the Photo-Sensitive Polymer SU-8 and Au MicroElectronic Engineering, 2005