PACKAGE ROBUSTNESS ENHANCEMENT: REDUCTION OF TRIM-INDUCED STRESS THROUGH REENGINEERING OF DAMBAR PUNCH

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ABSTRACT

In the semiconductor industry, package cracks remain a persistent issue, especially on the leads. These cracks often result from mechanical stress during the Trim and Form process.

To investigate high crack occurrences on a specific machine, a defect analysis and tool mapping were conducted to determine at which process step the cracks formed. Stress calculations were also performed to understand the forces acting on the package.

The study found that packages in a face-down or dead bug orientation were more prone to lead cracks. This vulnerability was linked to the thinner front-side package dimension compared to the back side, increasing stress during processing. The issue was worsened during dambar removal, where a blanking or rectangular punch design contributed to crack formation.

A redesigned dambar punch was implemented to reduce stress on the package by 33%. As a result, the Package Crack on Leads PPM significantly decreased by 98% in WWK51.

1. 0 INTRODUCTION

Cracked Package on the Leads side (CRPL) is among the most common mechanical defects encountered in semiconductor manufacturing. These cracks are primarily caused by mechanical stresses introduced across various processes and equipment in the assembly line. A recent spike in CRPL rejects was observed during the Trim, Form, and Singulation stage of the SOT1210 package assembly, originating specifically from a single machine. This also triggered frequent lagging OCAP hits, making it a clear focus for investigation.

Although the issue was localized to one tool, identifying the root cause remains challenging. CRPL defects are often too small to be detected by automated visual inspection systems. If undetected, these cracks may worsen as the package progresses through subsequent stages, further complicating traceability and root cause analysis.

Several published studies have identified mechanical mold flash removal and tooling-induced stress as major contributors to lead-side cracks. In one case, redesigning the punch tool significantly reduced stress during the trim and form process, leading to a marked reduction in lead cracking.

While these findings are valuable, the SOT1210 package has a unique process flow and structural characteristics. This study applies the DMAIC methodology to systematically identify the root cause of CRPL in this specific context. Leveraging insights from prior studies, the investigation includes process mapping, stress simulation, and tool design modifications to minimize stress on the package and reduce CRPL reject rates.

2. 0 REVIEW OF RELATED WORK

One of the common issues that the semiconductor assembly process encounters is package crack. It occurs when an external or internal force acts on the package causing it to overload and exceed its physical capabilities.

The usual cause of package cracks in the assembly line is when a mechanical part of the equipment hits the product causing a critical defect. This is a common phenomenon in the assembly process of Trim, Form, and Singulation where packages are subjected to different mechanical forces like bending, cutting, etc.

Based on a paper published in IEEE or Institute of Electrical and Electronics Engineers by De Guzman, Epistola, and Mena (1996), there is a risk of package crack when it undergoes mechanical deflash. The crack is not easily seen in the assembly process. However, if it undergoes thermal stress, the crack propagates until it is large enough to be seen or worse, reaches the die and causes die crack.

Another paper published in the 34th International Electronic Manufacturing Technology Conference by Uy, Picardal, Enriquez, and Alaraz (2010), focused yet again on the dambar punch of a package wherein it hits the flash completely which creates stress on the bottom package causing package crack shown on Figure 2.

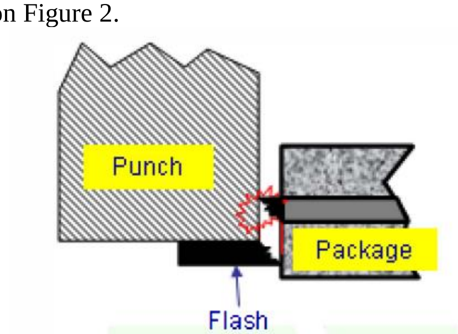


Figure 2. Is an illustration from paper of Uy, Picardal, Enriquez, and Alaraz (2010) where in the punch creates a crack on their sample unit.

3.0 METHODOLOGY

A crack can manifest when a strong external force directly hits the package. These can be seen mostly on the front part of the package. It can also be categorized into six types depending on where the crack is seen. Figure 3 and 4 shows the six types of package crack that the line encountered namely Cracked Package on Front (CRPF), Crack Package on Leads (CRPL), Cracked Package on Side (CRPS), Cracked Package Shattered (CRPSh), Cracked Package on Tab (CRPT), Cracked Package on Back (CRPB), and Cracked Package on ST1 or ST3 (CRP1) location.

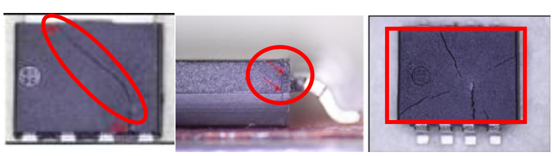


Figure 3 (from left to right) CRPF, CRPS, and CRPSh

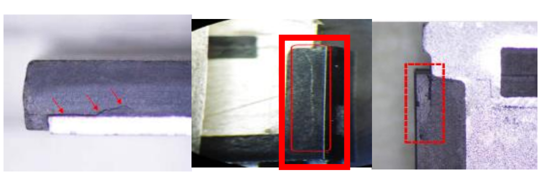


Figure 4 (from left to right) CRPT, CRPB, and CRP1

One of the critical defects detected on the line is Package Crack. There was a sudden increase of CRPL on SOT1210 lagging OCAP that was detected at QA Central Gate Inspection. Based on the rejects signature of the CRPL, the Package Crack that originates from the lead area propagating to the top of the package as seen on Figure 5. This increase in CRPL rejects on QA Gate Inspection in Figure 6 is also a sign that we also encounter an increase in CRPL rejects PPM per week resulting in yield loss as shown in Figure 7.

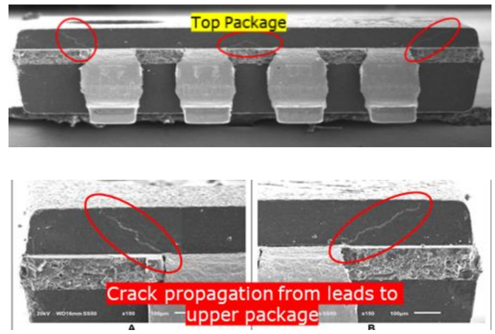


Figure 5 CRPL reject up-close

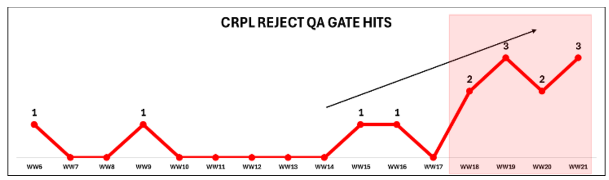


Figure 6. CRPL rejects detected at QA Gate Trend per week

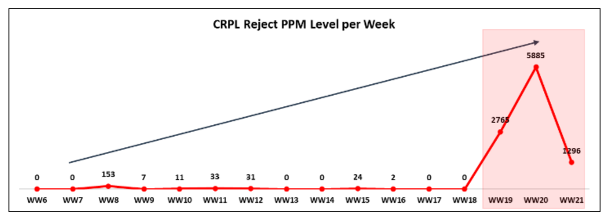


Figure 7. Overall CRPL reject trend per week

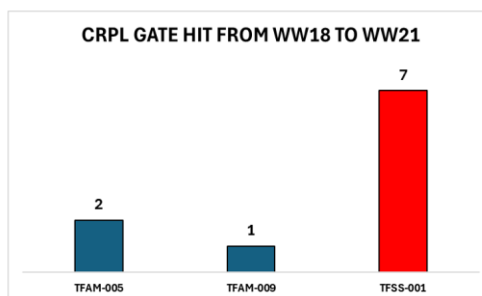


Figure 8. CRPL rejects occurrence per trim and form machine

Based on Figure 8 TFSS-001 was the highest contributor of CRPL rejects detected at QA Gate which caused the spike shown in Figure 6. For this reason, the study will be focusing on solving CRPL rejects from TFSS-001.

3.1 Tooling Mapping

TFSS-001 is a newly qualified machine model while TFAM-009 and TFAM-005 are the old machines that are currently qualified and have been used by the production line for years. The TFSS-001 also has three different tools compared to the two tools used by TFAM machines. The three tools serve different purposes which are Trim, Form, and Singulation. The tools will be mapped out to find where the CRPL occurs.

To do the tool contact mapping, a dummy leadframe will be used. The sample will be visually inspected first to ensure that all are free from package defects. After which, the sample leadframe will be processed on the first tool and inspected again but this time, to check if there are cracks in the leads area. The process will repeat until the sample leadframe is singulated.

The progressive mapping in Figure 9 shows that the CRPL occurs after Dambar removal process where in minute cracks start to appear at the side of the leads and can be seen through tilting inspection, in which crack continue to propagate and worsen after passing all the tools.

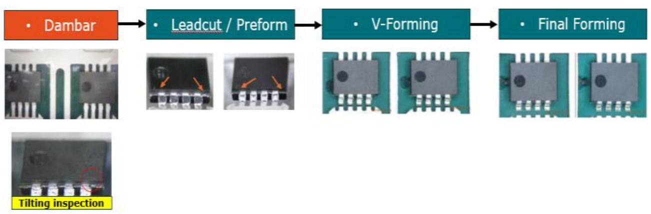


Figure 9. Reject progressive mapping from dambar to forming

3.2 Unit Analysis

Based on the CRPL units, the crack from the leads area propagated from bottom to the front surface of the package. Upon checking the package, the leads are located near the front area where the mold encapsulation is thin compared to the bottom area. The thin area makes the package weak when it is applied with an external force as shown in Figure 10.

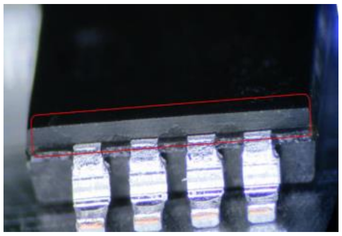


Figure 10. CRPL reject with crack located above the leads of the package.

3.2.1 Dambar Tool

The purpose of the dambar tool is to remove the metal piece or connecting bars in-between the leads in preparation for the Forming Tool. It clamps the leadframe and punches down the dambar which leaves the leads separated from each other. It also removes the excess mold flash in the package itself

Based on the mapping, the CRPL was replicated in the dambar tool of TFSS-001. Now, both TFSS-001 and TFAM machines have dambar removal process. However, TFSS-001 loads the package in a Dead bug or bottom-up position. While the TFAM machines are loaded in a live bug or top up position. In Figure 11 it is shown what a Dead bug and Live bug orientation looks like.

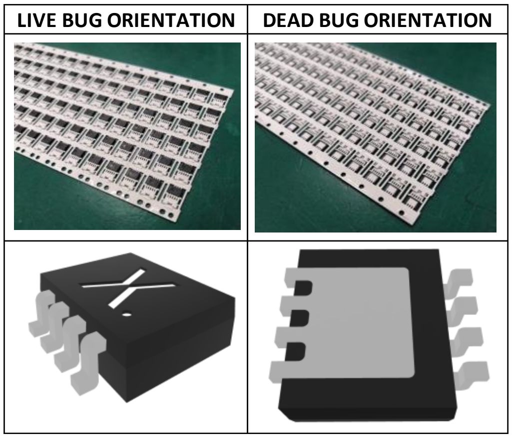


Figure 11 Live Bug and Dead Bug Loading orientation

3.2.2 Cross Section Analysis of SOT1210 Package

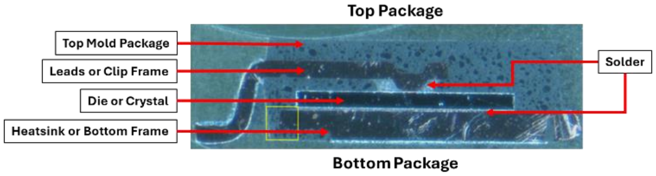


Figure 12 Cross Section Analysis of SOT1210 package

Based on Figure 12, SOT1210 package is thicker on the bottom compared to the top. This difference in thickness could possibly be a factor why CRPL signature is starting from the leads propagating to top package.

3.3 Force Analysis

A simulation was done to check the effect of orientation during dambar cutting using a Force Gauge. The gauge works by manually turning the leadscrew to apply increasing force on the sample. A jig was also used to create a three-point bend test on the units. Below in Fig 13 is the gauge and jig that were used in the experiment.

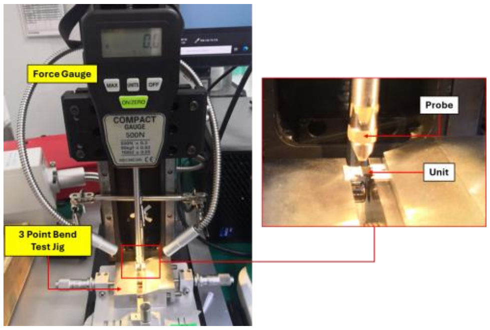


Figure 13 Force analysis set-up

The first setup was placing an untrimmed unit on the jig in a live bug position. The probe was used to bend the leads of the package as shown on Figure 14 while also recording the max force it gives. The instrument will only be stopped once the reading goes down and CRPL is produced.

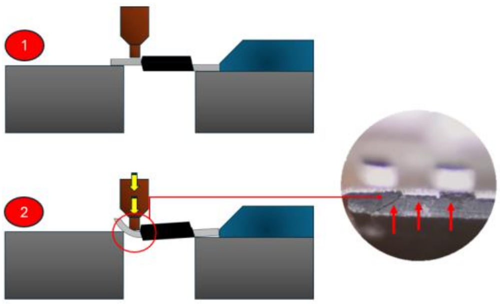


Figure 14. Different loading orientation with live bug on number 1, and dead bug on number 2.

Based on the results in Fig N., the average force required to bend the leads is 9.59N. The next setup is by placing a unit in a dead bug orientation which is what the TFSS-001 is using. The results on Table N. show that the average force is 3.56N which is relatively low compared to the live bug orientation.

A 2 sample T-Test was used to compare the data and check if the difference is statistically significant. In Figure 15. it shows that there is a large gap between the live bug and dead bug orientation.

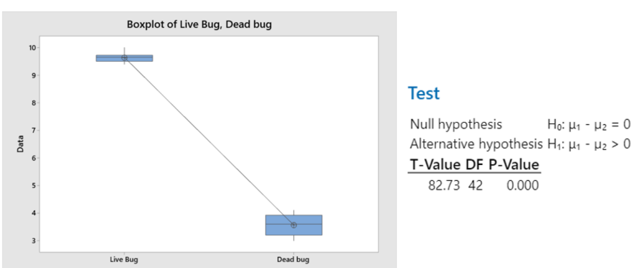


Figure 15 2 sample T-test of Live bug vs Dead bug force reading

For the 2 sample T-Test, the alternative hypothesis shows that the two means have a statistically significant difference such that the means of dead bug have smaller force needed to bend the leads compared to live bug. This shows that the TFSS-001 has a weak setup since it singulates the units in dead bug position. Changing the orientation of the package in the machine will require multiple design changes and higher costs for the replacement, which is not cost efficient for Nexperia. But not changing the current set-up will lead to product defects, which is unacceptable.

To resolve this, further analysis on the current dambar punch was made available. In Figure 16, shows how the punch removes the dambar and mold flash in the package.

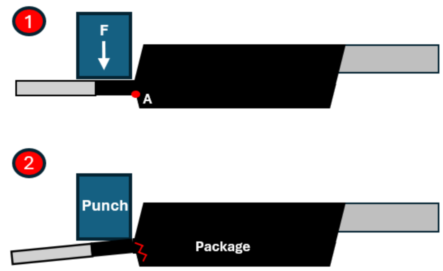
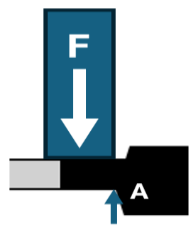


Figure 16. The punch aligns with the dambar and mold flash in number 1 and punches simultaneously in number 2.

Based on the illustration, the part of the dambar punch intended for mold flash removal was also punching a portion of the dambar which may explain why it has many hits of CRPL. To further prove it, a Free-Body Diagram or FBD is created. The purpose of this analysis is to understand how the force from the punch can potentially weaken the package.

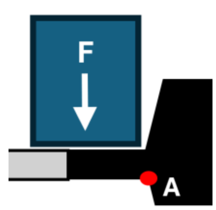


$$\sum M_A = \frac{wL^2}{2}$$

Figure 17. (Left) Shows a uniformly distributed downward force being applied on the dambar and mold flash which creates stress on point A. (Right) Shows the computation to get the bending moment at point A.

Figure 17 can be analyzed the same way as a cantilever beam with a force applied on the beam, only this time, the wall is the package which holds the flash in place. However, the force applied on the flash is shaped as a rectangular punch to which getting the total force will be multiplying the force applied to the length of the punch.

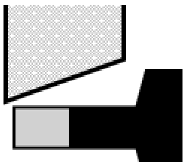
The bending stress can be expressed in Figure 18, where the stress is high if the bending moment (M) is also high. To resolve this issue, the bending moment should be lowered. It also means that the dambar punch must be redesigned to reduce the force and stress that it applies.



$$\sigma = \frac{Mc}{I}$$

Figure 18. (Left) As the force on the punch moves down, stress is created at point A where it can be computed using the formula (Right) for the bending stress.

The best way to reduce force and stress is by changing the punch design from a flat cutting punch to an angled punch to cut the dambar and punch gradually or progressively with this, the total force applied can be computed shown in Figure 19.



$$\sum M_A = \frac{wL^2}{6}$$

Figure 19. (Left) A new triangular dambar punch to which the total load (Right) it can be computed using the new bending moment formula.

It shows that the total force applied on the unit is much smaller which also reduces the bending stress. It also shows that the punch will now remove first the dambar which makes the flashes easier to remove as the punch moves down.

4.0 RESULTS AND DISCUSSION

Due to the relatively thin mold flash which the force gauge will not be able to measure the difference of the two punch design, mathematical calculations (refer to APPENDIX A) were done to check the impact the new dambar punch to the stress on the package. The results show that the new punch reduces the stress on the package by 33% compared to the blanking punch design.

A simulation was also done using Autodesk Inventor to show the comparison of the stress from the existing dambar punch and modified dambar punch as shown in Figure 20 and 21 respectively. The simulation on Figure 20 shows that using the existing design of dambar punch can stress the molded package during dambar cutting process compared to the modified dambar punch design.

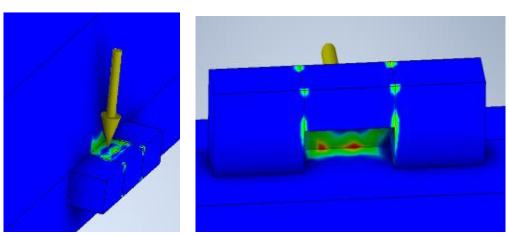


Figure 20. (Left) Applied force on the flash which represents the total load of the punch. (Right) The view from below the flash shows red marks indicating there is a high stress on the package.

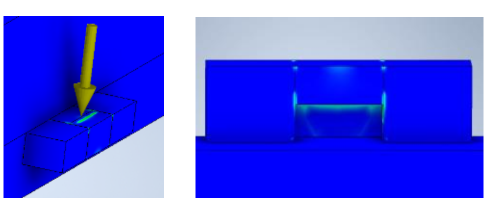


Figure 21. (Left) Force applied on the edge of the flash using the triangular punch has visibly no stress on the package. (Right) View from below the package which has no stress on the edge of the package.

CSAM was conducted to the samples units processed using existing dambar punch and modified dambar punch design to further visualize the CRPL produce during trials, Delamination was seen on the samples on Figure 22 as indicator for CRPL, while no delamination seen on Figure 23

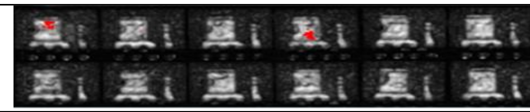
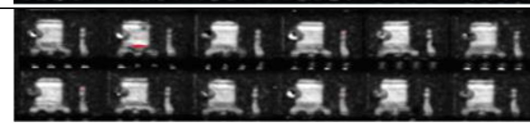
Trial	CSAM Result
1	
2	

Figure 22. CSAM Result of units processed using existing dambar punch design.

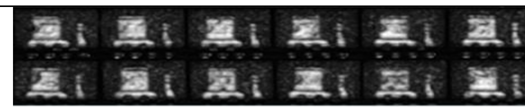
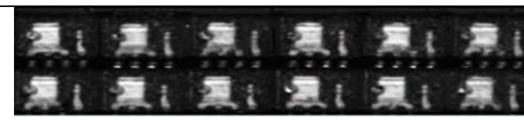
Trial	CSAM Result
1	
2	

Figure 23. CSAM Result of units processed using Modified dambar punch design.

The modification of Dambar punch for SOT1210 project was enrolled in the Quality Control Management or QCM with ID MC-20230607-34 as part of documentation and control in the Nexperia. This improvement in the tooling design was documented on the Nexperia Document System and included in the Purchase Order Specs Harmonization as reference for future purchasing of new machines and tooling.

This project normalized the CRPL reject intercepted at QA gate inspection as well as the Reject PPM level for SOT1210 package as seen on Figure 24 and 25.

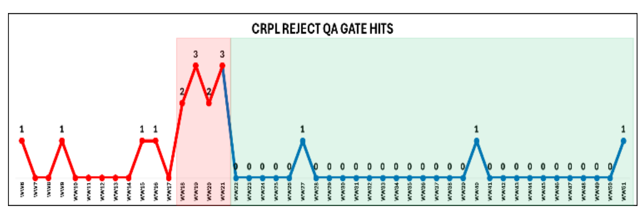


Figure 24. CRPL rejects detected at QA Gate Trend per week

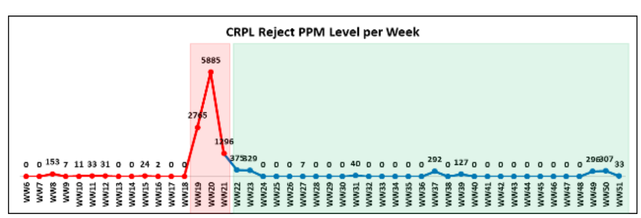


Figure 25. Overall CRPL reject trend per week

5.0 CONCLUSION

To reduce the CRPL hits, the dambar punch needed to be modified. The design of the punch lessens the force applied on the dambar and mold flash which reduces the stress that is being transmitted on the package. It also cuts down the dambar first which makes the flashes easier to remove as the punch moves down.

6.0 RECOMMENDATIONS

One of the most common and critical defects in the semiconductor industry is package crack. Which is why there is a need to benchmark on the current tooling designs and technology to reduce and eliminate package cracks. A good way to do it is by reviewing different studies made by other engineers and alike that is readily available on the internet.

In addition, the root cause of the problem was identified to be the design of the dambar punch. It means, there is a need to extensively study the tooling design through computer simulations and conduct force measurements to prevent creating package defects.

7.0 ACKNOWLEDGMENT

The authors would like to express their gratitude to the technical analysis and lab instruments used from Nexperia (ATCB) – Failure Analysis Group. The Process, Tooling and Equipment Engineering Team for supporting in conducting field experiments in the Trim, Form, and Singulation Area.

8.0 REFERENCES

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2. A. Uy, M. Picardal, P. Enriquez and A. Alaraz, **Package Crack Resolution Through Low Stress Dambar Punch Design: A Six Sigma DMAIC Approach**, 34th International Electronic Manufacturing Technology Conference, **2010**, pp 5

9.0 ABOUT THE AUTHORS

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Freddie Belwang is an experienced engineering professional with over 20 years in the semiconductor industry. He holds a diploma in Tool and Die Technology from Dualtech Training Center Foundation Inc. and a Bachelor of Science in Mechanical Engineering from Manuel S. Enverga University Foundation. Freddie began his career at Nexperia as an Equipment Engineer, focusing on the qualifications of new equipment and tooling. He now serves as the Trim and Form Sustaining Processing Engineering Manager.

7.0 APPENDIX

APPENDIX A – PUNCH BENDING MOMENT COMPUTATION

$\sum M_R = \frac{wL^2}{2};$ → Bending moment for Rectangular Punch

$\sum M_T = \frac{wL^2}{6};$ → Bending moment for Triangular Punch

$w = \frac{2M_R}{L^2};$ → Express equation in terms of w

$M_T = \frac{(2M_R)(L^2)}{(L^2)(6)};$ → Substitute w to Bending moment for Triangular Punch

$M_T = \frac{2M_R}{6};$ → Eliminate L^2

$M_T = \frac{M_R}{3};$

$M_T = 0.33M_R;$ → 33% of bending moment of Rectangular Punch