SYSTEMIC APPROACH ON ROOT CAUSE ANALYSIS OF BANDGAP FAILURE FOR YIELD IMPROVEMENT OF QFN DEVICES

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ABSTRACT

A Quad Flat No-lead (QFN) product with package dimension of 5x5mm and 7x7mm has been introduced as the start of qualification device at the new assembly plant from Microchip Technology Philippines (MPHIL3). During the product qualification, the qualification lots produced by MPHIL3 failed to reach the target yield of 98%, and it was attributed to the high parametric failure observed at test where the failure was identified as bandgap. With the problem at hand, the authors are enthusiast to find out the root cause of bandgap by understanding the nature of its rejection, identifying, and validating the potential contributors of the defect from the assembly, and to recommend actions that would mitigate the bandgap failure to reach the target yield goal. Through the systematic analysis of root cause covered in this study, the authors concluded that the bandgap failure was induced by the unit exposure to X-Ray. By the end of this paper, the authors have proved that the root cause was identified which pushed the implementation of actions that made the qualification of the QFN devices successful.

1. 0 INTRODUCTION

Microchip Technology Philippines (MPHIL3) was introduced with a new product assembly line of Quad-Flat No Lead (QFN) in the Philippines. Devices that are built in MPHIL3 are transferred from Microchip Thailand to support the production expansion of Microchip Products.

Various QFN devices have started the qualification with the 5x5mm and 7x7mm package size. During the initial stages of qualification, a yield target of 98% was not met which fails the qualification criteria, and the highest rejection was accounted with bandgap failure.

Band gap rejection happens when the unit has out-of-range voltage reading than the required and identified range. According to reference studies, there are devices that are possibly at risk of being damaged by ionizing radiation[1]. There are also related studies which discuss the reason for damage and degradation of units can happen due to long term exposure to x-ray[2-4] as electronic devices have changes on the electrical properties when subjected with radiation[5]. These references are in the interest of the authors for validation and analysis throughout the study.

In Figure 1, the target yield was shown to be not met. In Figure 2, a pareto chart where band gap failure occupies the highest rejection.

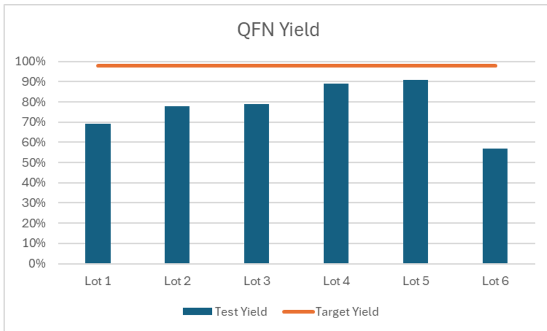

Fig. 1. Graphical representation of the yield gap between the target yield of 98% vs the Actual Yield Average of 77%.

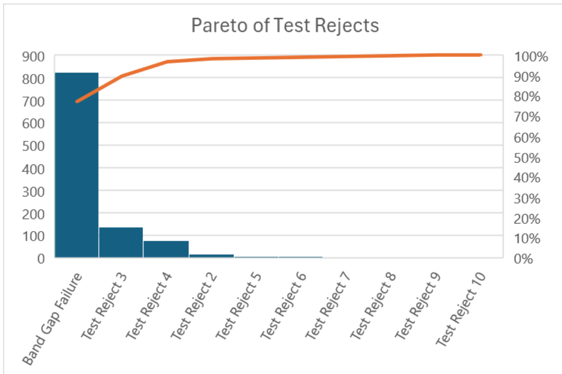

Fig. 2. Graphical representation of the test reject distribution for QFN 5x5mm and 7x7mm Package. Band Gap Failure is the top defect compared to the other test rejects from the qualification lots.

Band gaps are only detected in test which results as a parametric failure. Units that are rejected with band gap failures are subjected to reliability without any noted abnormalities on the cosmetics of the unit thus, band gap failures are not detectable during the assembly processes from die preparation until strip test. Shown in Figure 3 is the assembly and test process flow for QFN.

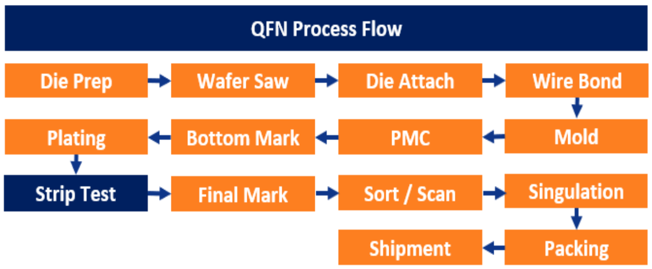

Fig. 3. General Process flow of the QFN under Strip Test Flow.

Strip testing is where the strips are tested in strip form. The units with rejection at test and the corresponding strips can be traced within the test system. Band gap failure was entrapped on the strip test station.

With the problem at hand, the QFN team focused on the identification of the root cause of the band gap failure, with the aim to improve and hit the target yield.

2. 0 REVIEW OF RELATED WORK

Refer to 1.0 Introduction.

3.0 METHODOLOGY

The authors are driven to perform simulations and validations to identify the root cause of band gap with the goal to apply actions that would mitigate the rejections and improve the yield for the affected device.

3.1 Understanding the Band Gap Failure

Band gap failure is a condition where the voltage reading in the unit during test is lower than the range of voltage that the unit requires. Band Gap failures are the response from the die upon testing for the circuitry. Figure 4 shows the representation graph to explain the band gap failure.

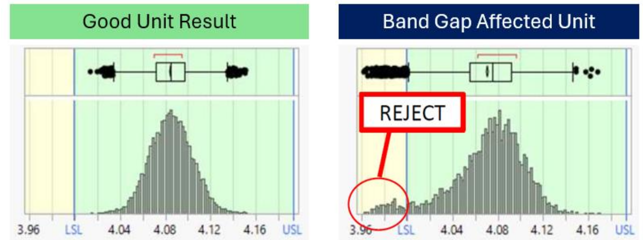

Fig. 4. Band gap failure lies on the out-of-specification range of the voltage reading of a unit.

Good units possess voltage reading within the specified Upper Specification Limit (USL) and Lower Specification Limit (LSL). However, band gap failure displays reading beyond the LSL. Failure to meet the voltage requirements results in parametric failure and may further result to Open/Short (O/S) rejection as an open unit. Units with open failure have a disconnection with the circuitry.

3.2 Band Gap Failure Unit Mapping and Traceability

The authors considered reject mapping to verify localization and commonality. Upon investigation of the affected strips, it has been found out that the rejected units are not localized. Figure 5 shows the sample mapping of the strips with band gap rejection as gathered on the qualification lots processed under QFN package.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	-1	2	146	2	2	2	2	2	2	2	2	2	623	602	623	146	146	623	623	146	384	2	2	623	2	2	2	2	2	602
2	623	623	2	623	623	2	623	623	2	2	2	2	146	146	2	623	623	146	146	146	623	2	2	623	2	2	2	623	2	2
3	623	2	2	602	2	2	623	2	2	623	602	2	623	146	146	146	623	623	146	146	623	2	602	146	2	602	2	2	2	2
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5	2	602	2	2	2	623	623	623	623	2	2	2	2	623	623	623	2	2	623	2	2	146	623	2	2	2	2	2	602	623
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7	2	2	623	2	2	2	2	2	623	2	617	282	2	2	2	2	282	2	2	2	146	623	2	623	623	2	2	623	623	2
8	-1	2	623	623	2	2	2	2	2	602	623	2	623	2	2	623	623	2	623	2	2	602	2	2	2	623	2	-1	2	2

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	2	146	623	146	146	623	602	2	2	2	2	2	2	2	623	2	2	2	282	623	2	146	-1	900	602	2	623	623	2	623
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4	2	2	146	602	146	623	2	2	623	623	623	2	2	623	2	2	623	2	2	2	602	623	2	623	2	623	623	2	2	2
5	2	623	623	623	602	2	623	623	623	623	146	623	2	146	146	623	623	2	623	2	146	146	623	146	146	623	623	146	146	2
6	2	2	2	623	-1	146	2	2	623	282	623	623	2	602	2	2	2	2	623	623	623	623	2	146	146	146	623	146	2	623
7	2	2	623	623	2	623	623	146	623	623	146	146	2	623	146	2	623	623	2	2	602	2	2	146	146	900	146	146	623	623
8	602	2	2	623	623	2	2	623	2	602	2	623	623	146	2	2	602	2	2	2	623	2	623	-1	-1	146	146	146	623	146

Fig. 5. Reject mapping of band gap rejection represented by red and dark red units on the strip mapping. There is no unit localization on the rejected units as per strip test results.

The unit traceability was worked out to be traced back on the wafer level. However, data from qualification lots shows that there is no commonality from the wafers where the rejected units came from.

The assembled units of QFN devices were compared with the data from other Microchip Plants that manufactured the same

QFN device. MPHIL3 is the only affected plant for the gross band gap rejection.

3.3 Process Flow Mapping and Commonality Analysis

Through the methodologies performed in understanding the nature of the band gap failure, the authors proceed to investigate the assembly process flow and commonality analysis that would help to figure out the cause of the issue.

Upon analyzing the assembly process flow, the authors found out that there are significant discrepancies between MPHIL assembly compared with the other Microchip Plants. Shown in Figure 6 is the QFN Process flow to represent the identified process stations where the discrepancies are found.

These discrepancies have been opportunities for the authors to conduct further study, aiming to find the source of band gap failures.

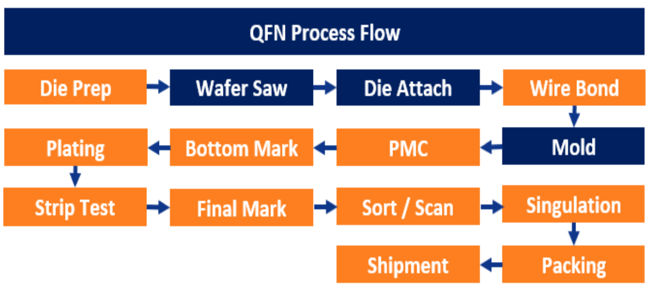

Fig. 6. QFN Process Flow with significant discrepancies found for investigation and commonality analysis.

The first identified discrepancy is the used water resistivity parameter range on Wafer Saw process. Other Microchip plants use 0.25 to 0.35 MOhm of resistivity while MPHIL3 uses 0.55 to 0.60 MOhm. It has been suspected that the resistivity of water used at wafer saw process is high which results with the band gap after the unit assembly.

Another identified discrepancy is the subjection of the strips at X-Ray exposure on die attach and mold. Normal production procedure of the QFN devices do not require X-Ray after die attach, and mold has sampling inspection only. However, due to the tight inspection and verification, X-Ray was conducted to verify the occurrence of epoxy voids and wire related issue after mold application.

4.0 RESULTS AND DISCUSSION

Through the methodologies, it has been identified that the band gap failure can only be detected at test which will be the means of measurement for the validation effectiveness.

The nature of the band gap rejection is not localized and common with the wafer level and strip level. The occurrence is identified to be induced upon the unit assembly at MPHIL3.

The identified methodologies have resulted in narrowing down the analysis to arrive on the validation of the discrepancies observed within the process mapping.

4.1 Validation on the Effect of Water Resistivity

The authors proceed to validate the effect of water resistivity on the units. Table 1 shows the water resistivity from different Microchip plants.

Table 1. Water Resistivity

Plant	Water Resistivity
Microchip Plant 1	0.30 - 0.35 Mohm
Microchip Plant 2	0.25 - 0.30 Mohm
MPHIL3	0.55 - 0.60 Mohm

The authors validate the effects of water resistivity as benchmarked from Microchip Plants 1 and 2. The Authors proceed to apply 0.2MOhm and 0.3MOhm water resistivity for both 5x5mm and 7x7mm devices.

The result of the study showed that there is no significant difference on the data of band gap failure yield as attributed with the water resistivity. Shown in Figure 7 is the statistical analysis for the result of water resistivity.

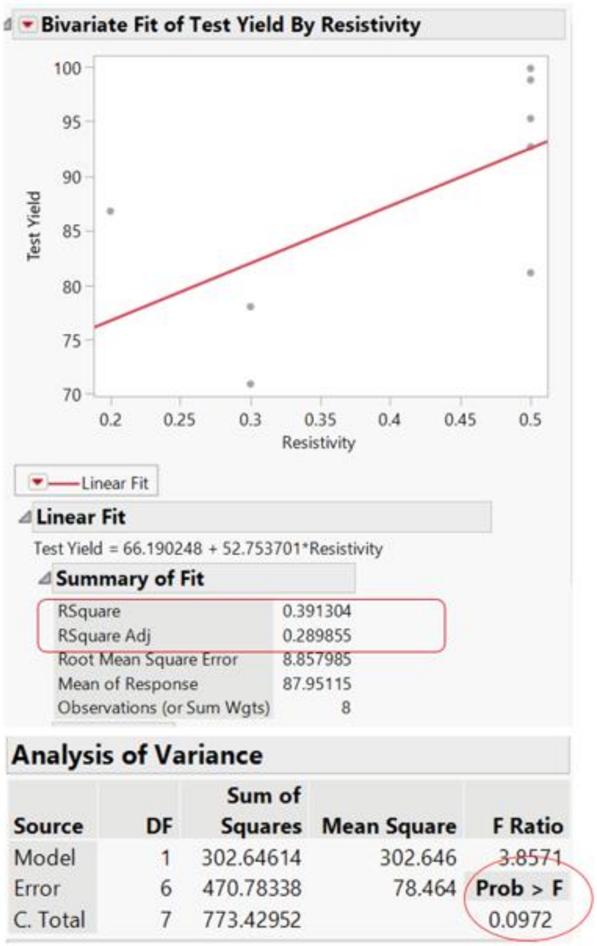

Fig. 7. Statistical analysis shows that there is no significant difference between the water resistivity set-ups regarding the band gap failure occurrences.

Based on the statistical results with P-Value >0.05, water resistivity has no significant effects on the band gap failure occurrences and thus is not a valid root cause of the problem. Correlation was not found between the water resistivity and the band gap occurrences with low attribution of 39% based on the statistical analysis results.

4.2 Exploring the Effects of X-Ray Exposure

The authors proceed with the validation of X-Ray. One strip affected with band gap failure that has been subjected with further X-Ray after strip test. Shown on Figure 8 is the aggravation of the band gap failures after application of X-Ray.

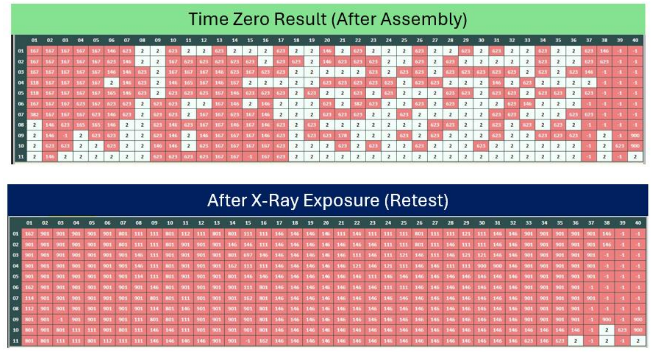

Fig. 8. Comparison of a single strip before and after further subjection to X-Ray exposure.

Initially, the strip garnered 45.2% yield after Time Zero (T0) assembly process. The strip has undergone X-Ray at Die Attach and Mold as part of verification. However, after further subjecting to X-Ray, the yield dropped down to 0.98% where the additional rejection was attributed to band gap failure. It has also been observed that the band gap failure was developed into O/S Failure upon further X-Ray exposure.

The validation has proven that the X-Ray contributes highly to the occurrence of band gap failure. The next step of the authors is to validate the identifies root cause.

4.3 X-Ray Exposure Time Evaluation

With X-Ray exposure as identified the root cause and main contributor for the band gap failure, the authors and process experts from mold and die attach have focused on the validation of effects of X-Ray exposure time.

Table 2 shows the summary of results on the exposure time and the corresponding band gap occurrence.

Table 2. X-Ray Exposure Time

X-Ray Exposure Time	X-Ray Die Attach	X-Ray Mold	Band Gap Failure	Result
60 Mins	Yes	Yes	28%	With Band Gap
	No	Yes	6%	With Band Gap
30 Mins	Yes	Yes	10%	With Band Gap
	No	Yes	9%	With Band Gap
15 Mins	No	Yes	2%	With Band Gap
3 Mins	No	Yes	1%	With Band Gap
0 Mins	No	No	0%	No Band Gap

X-ray exposure time of 60 minutes and 30 minutes were applied on the die attach while the strips are still not molded. Band gap results are high on the units with x-ray exposure on die attach and mold. On the other hand, absence of x-ray exposure at die attach mitigates the occurrence of the band gap failure.

Evaluation on 15 minutes and 3 minutes exposures resulted with minimal band gap failure occurrences. 15 minutes of exposure is doable at x-ray during the production run but poses risk for all the units exposed at x-ray. 3 minutes time limit for unit exposure is challenging for the users, however, still poses risk on the units as x-ray was done in a strip form.

Parameters on x-ray were not changed as it was optimized to be the best and most effective setting for inspection. Changing of x-ray parameters results in blurred image during inspection, yet the exposure is still present.

4.4 Validation on the Identified Root Cause

The result of x-ray exposure evaluation has been validated with 15 minutes inspection time to simulate the production capability. Shown on Figure 9 is the validation result.

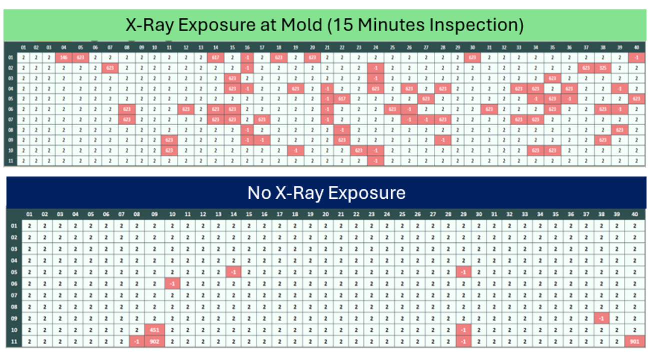

Fig. 9. Validation results of X-Ray Exposure at 15 minutes and No X-Ray Exposure.

X-ray exposure of 15 minutes after mold has been proven to have few units affected of band gap failure. On the other hand, the strip that was not exposed at x-ray has a cleaned test result without any band gap failure occurrence.
No exposure at x-ray is the best option that can be considered according to the result of x-ray exposure evaluation. X-ray exposure completely puts the units on risk for band gap failure. However, x-ray inspection is required to ensure the good quality of the units produced.

4.5 Implementation of Mitigation Plan and Results Monitoring for QFN Device

The results of validation have driven the process experts and the management to implement no x-ray inspection on the good lots. Verification and inspection of strips are managed on a built dummy strip to avoid exposure of good lots at x-ray while ensuring the quality of the produced products.

A new qualification lot was initiated by the QFN team to push through with the development of QFN device. Without x-ray inspection, band gap failure resulted from 27% to zero.

Engineering lots were released for assembly to support the investigation of band gap failure. Figure 10 shows the monitoring results gathered by the mold process engineering with the development of the band gap investigation.

Fig. 10. Validation results of X-Ray Exposure at 3 minutes and No X-Ray Exposure.

The monitoring of band gap failure has proven that x-ray exposure is the root cause of the problem, and the yield can be improved through the implementation of no x-ray inspection on good lot run.

5.0 CONCLUSION

Band gap failure occurrences are proven to be induced by the exposure of the units at x-ray. Removing the x-ray exposure at good units resulted in the yield improvement from 77% to reach more than the target yield of 98%.

Through the methodology and results of the validations conducted in this study, it has been concluded that x-ray exposure on die attach and mold contributes to the occurrence of band gap failures. On the other hand, water resistivity has no significant effect to contribute to the failure.

It is therefore concluded that the root cause of the band gap failure has been identified and proven.

6.0 RECOMMENDATIONS

With the results and conclusions drawn on the study, the authors recommend to further conduct study focusing on the discovery of the x-ray grammage that imposes risk for band gap failure occurrences. The authors also recommend discovering new methods, materials, and practices to mitigate the effects of x-ray exposures to the units.

7.0 ACKNOWLEDGMENT

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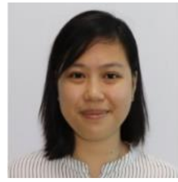

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