RF DS Yield Improvement through ZONAL Technique for pHEMT Product

Yiping Wang[1], Pat Hamilton[1], Robert Waco[1], Jeremy Middleton[1], Frank Barnes[2] and Andrew Choo[3]

[1]Qorvo, Inc., 2300 NE Brookwood Parkway, Hillsboro, OR 97124
e-mail: Yiping.Wang@Qorvo.com, Phone: +1 503-615-9264
[2]Qorvo, Inc., 500 W Renner Rd, Richardson, TX 75080
[3]UP! Strategies Consulting, 15875 Boones Ferry Rd #2102, Lake Oswego, OR 97035.
e-mail: andrew@upstrategiesconsulting.com, Phone: +1 503-970-1197

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Abstract

This paper outlines applying ZONAL technique to identify the root cause on RF Die Sort (DS) yield loss at Qorvo and further narrow down to the process step to make process adjustments as required. The data analysis software Spotfire (TIBCO®) enables us to group dice spatially on a wafer map view of test data and apply the groupings for further correlation analysis. The key idea of ZONAL technique was to associate dice around Process Control Monitor (PCM) test structures with respective PCM sites for correlation analysis. By correlating DS critical parameters with PCM parameters using this technique, we were able to find the specific layer and potential root cause. It is more efficient than traditional wafer level average correlation.

In this paper, the application of ZONAL technique on improving RF DS gain yield is described. Our experience has shown us, that ZONAL analysis is a very powerful data mining technique which will enable significant time savings for yield engineers to drive yield enhancement. More important, quickly identifying the root cause of yield loss will be a tremendous cost saving for the company.

INTRODUCTION

Gain value resulted from RF Die Sort (DS) testing is a main electrical performance spec on one of our pHEMT products. Starting the last quarter of 2015, gain yield showed a dynamic up and down trend with a relative magnitude of 95% drop in the worst case as shown in Fig. 1.

Preliminary data analysis was performed and the root cause was not identified. There was no correlation observed between RF DS results and Process Control Monitor (PCM) data at all based on wafer level aggregation.

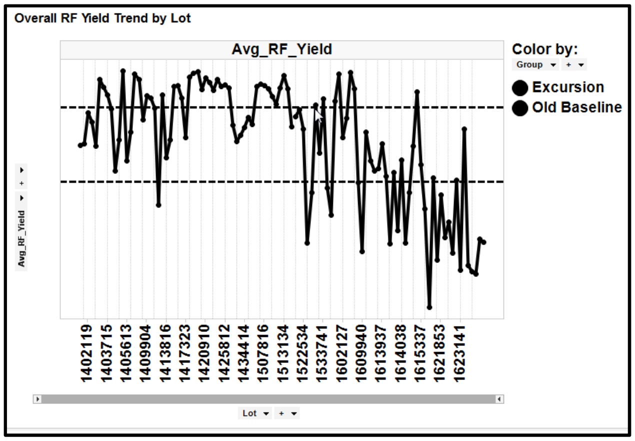


Fig. 1. RF Yield Trend on Product A by Lot Number.

To get away from the dilemma, a systematic approach, also known as **ZONAL** (**ZON**E AN**AL**YSIS) technique was applied.

The ZONAL technique was originally developed by Pat Hamilton and Andrew Choo at TriQuint (currently Qorvo) after TIBCO Spotfire data analytics platform (TIBCO®) [1] was introduced in 2007 [2]. The technique arose from the need to correlate DS parametric test data measured on completed wafers against data from PCM test structures (also known as sites) at both DC and RF test points. The goal was to determine the root cause for yield loss at DS that has either a process interaction or process tool correlation. At DS testing, all complete dice on a wafer are tested, resulting in a relatively large volume of data. While at PCM test, only nine (9) sites on a wafer are tested. Comparing data using wafer averages/medians at DS versus PCM did not yield clear correlations due to variation or clamping of measured data across a wafer. In Spotfire, electrical DS data are represented as wafer maps, from which we can spatially group dice surrounding each individual PCM site using the Data Tagging feature in Spotfire and define those dice as ZONAL dice. Further correlation will be performed only between ZONAL dice and PCM sites in the same ZONEs.

This method of sampling groups of dice near each PCM test structure assumes that the performance difference between dice adjacent to a PCM test site will be less than dice located further away from a given PCM test site. This unique sampling approach effectively increased both the resolution and contrast of the analysis results. In this case, each wafer yields nine data points for correlation, versus just one when wafer averages are used.

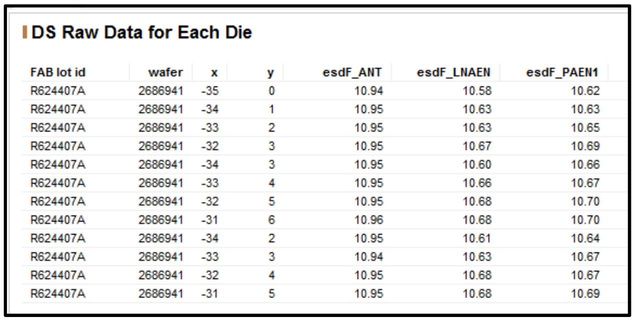
In the following sections, the detailed procedures and implementations on ZONAL technique are described.

Implementation of the ZONAL Technique Using Spotfire

At Qorvo, DS and PCM raw data by each die and PCM site are stored in a database. To use the ZONAL technique, the raw data needs to include (x,y) coordinates for dice and (X,Y) coordinates for PCM sites. The detailed procedures are described as the followings:

Step 1: Extract DS raw data into Spotfire from the database in PIVOT format (i.e. short-wide).

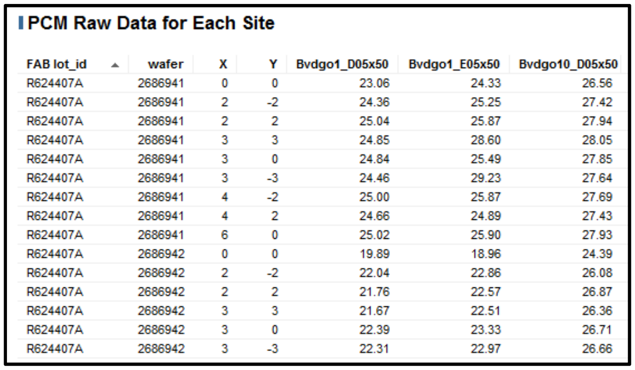
TABLE 1.
DS RAW DATA FOR EACH DIE


DS Raw Data for Each Die

FAB lot id	wafer	x	y	esdF_ANT	esdF_LNAEN	esdF_PAEN1
R624407A	2686941	-35	0	10.94	10.58	10.62
R624407A	2686941	-34	1	10.95	10.63	10.63
R624407A	2686941	-33	2	10.95	10.63	10.65
R624407A	2686941	-32	3	10.95	10.67	10.69
R624407A	2686941	-34	3	10.95	10.60	10.66
R624407A	2686941	-33	4	10.95	10.66	10.67
R624407A	2686941	-32	5	10.95	10.68	10.70
R624407A	2686941	-31	6	10.96	10.68	10.70
R624407A	2686941	-34	2	10.95	10.61	10.64
R624407A	2686941	-33	3	10.94	10.63	10.67
R624407A	2686941	-32	4	10.95	10.68	10.67
R624407A	2686941	-31	5	10.95	10.68	10.69

Step 2: Extract PCM raw data into Spotfire by PCM sites for the same wafers from Step 1 in PIVOT format also.

TABLE 2.
PCM RAW DATA FOR EACH PCM SITE


PCM Raw Data for Each Site

FAB lot_id	wafer	X	Y	Bvdgo1_D05x50	Bvdgo1_E05x50	Bvdgo10_D05x50
R624407A	2686941	0	0	23.06	24.33	26.56
R624407A	2686941	2	-2	24.36	25.25	27.42
R624407A	2686941	2	2	25.04	25.87	27.94
R624407A	2686941	3	3	24.85	28.60	28.05
R624407A	2686941	3	0	24.84	25.49	27.85
R624407A	2686941	3	-3	24.46	29.23	27.64
R624407A	2686941	4	-2	25.00	25.87	27.69
R624407A	2686941	4	2	24.66	24.89	27.43
R624407A	2686941	6	0	25.02	25.90	27.93
R624407A	2686942	0	0	19.89	18.96	24.39
R624407A	2686942	2	-2	22.04	22.86	26.08
R624407A	2686942	2	2	21.76	22.57	26.87
R624407A	2686942	3	3	21.67	22.51	26.36
R624407A	2686942	3	0	22.39	23.33	26.71
R624407A	2686942	3	-3	22.31	22.97	26.66

Step 3: Plot a scatter graph using DS raw data to show the wafer map by (x,y) coordinate and stack all the wafers being analyzed

Step 4: Select or highlight those dice around PCM sites and tag them as 'ZONAL' dice. Using Data Tagging to filter to the selected dice (Fig. 2)

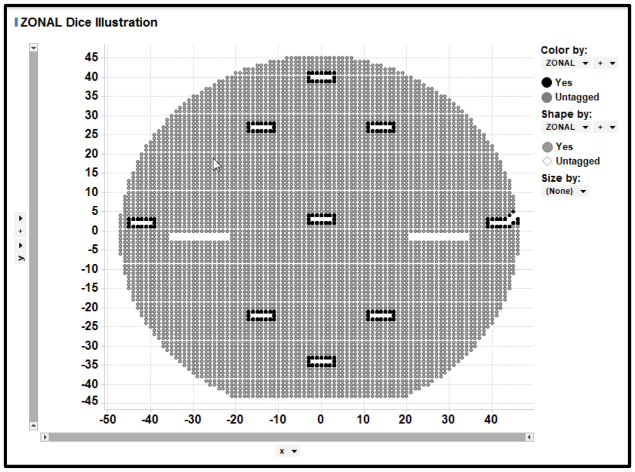


Fig. 2. Illustration of ZONAL Dice.

Step 5: Develop a mathematical formula to translate ZONAL dice from (x,y) coordinates within wafer into the (X,Y) coordinates for PCM sites. The specific mathematical equation will depend on the configuration of PCM sites, therefore it will be case by case.

Step 6: Calculate the DS parameters aggregation (mean, median) on ZONAL dice by PCM coordinates for each wafer, and join DS ZONAL dice data with PCM raw data by lots, wafers and sites.

Step 7: Perform the linear or other correlation between the specific DS parameter and PCM parameters. For linear correlation, Spotfire will display the correlation by Rsquare in descending order.

ZONAL Application on Investigating RF DS Yield Loss

Starting late 2015, a Qorvo pHEMT product started showing a RF DS yield drop. The dominant yield inhibitor was RF gain value, which failed the lower spec limit (Fig. 3).

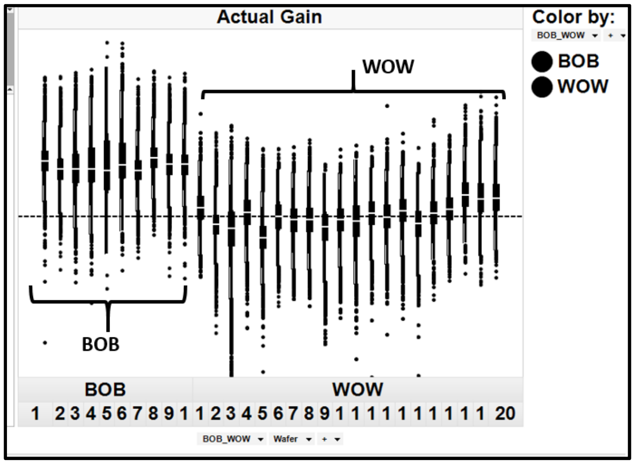


Fig. 3. Gain Value Distribution by Wafer.

By applying ZONAL technique on the best-of-the-best (BOB) and the worst-of-the-worst (WOW) populations, the potential root cause was explored and it turned out that lower gain value was strongly correlated to higher Cgs value (Capacitance between gate and source) from PostCap RF testing as shown in Fig. 4. Based on our technology development work done before, C_{gs} is a strong signal showing gate length variation [3].

Enlightened by this observation, we started an experiment on an engineering lot by varying the photo exposure at a pivotal step in the process that sets the final transistor gate length, i.e. critical dimension (CD). The lot was split into groups of wafers with a different photo exposure for each group to achieve a different final transistor gate CD. After the lot finished the fabrication process, it was tested and analyzed at RF DS. Based on the parametric data and yield, a target CD was determined and further process change procedures were followed. The optimized process is now released to production and the RF DS gain and yield have since fully recovered (Fig. 5).

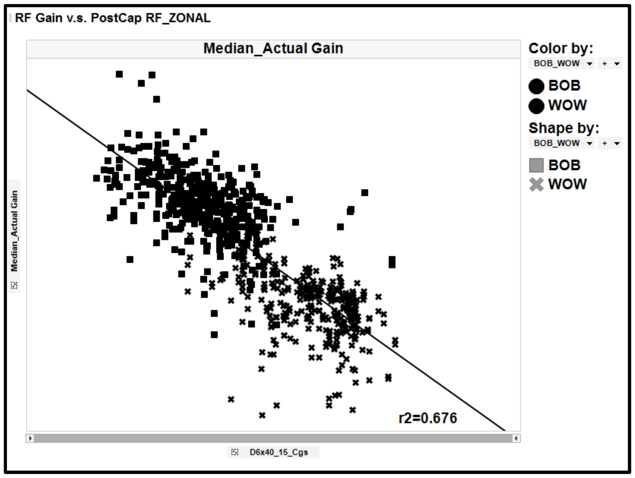


Fig. 4. Linear Correlation between Gain (Median) and Cgs.

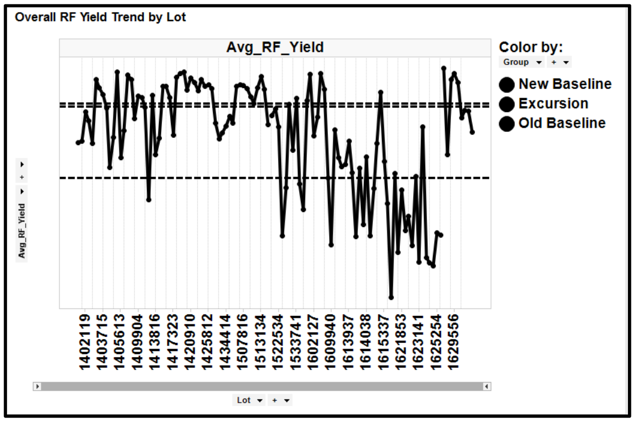


Fig. 5. RF Yield Trend on Product A by Lot Number.

CONCLUSIONS

The ZONAL analysis is a very powerful and efficient technique for yield engineers to investigate the product dice yield loss. It is more meaningful to characterize the dice near PCM sites so that process interaction or tools issues can be easily identified.

Besides the application addressed in this paper, we have applied ZONAL technique to identify the root cause of yield loss mechanisms on multiple scenarios and it was a significant time saving for yield engineers and cost saving for the company.

REFERENCES

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ACRONYMS

ZONAL: Zone Analysis
pHEMT: Pseudomorphic High-Electron Mobility Transistor
DS: Die Sort
RF: Radio Frequency
PCM: Process Control Module
BOB: Best of Best
WOW: Worst of Worst
C_{gs}: Capacitance between Gate and Source