Implementation of a Supplier Ship-To-Control Methodology and Resulting Improvements at Qorvo

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Abstract

Qorvo implemented a ship-to-control (STC) methodology where control limits are set around the Certificate of Analysis data and other Supplier SPC data. The supplier data is also uploaded to Qorvo databases for correlations to Fab process data. This methodology has reduced Material related yield loss and increased the speed of troubleshooting and learning.

INTRODUCTION

The impact of incoming material variation on fab yield is often underestimated. Fabs tend to assume a particular material is largely a fixed entity with minimal batch to batch variation. However this is very far from the truth. Even single element metal targets can be different batch to batch in purity, grain size and other detailed material characteristics that can affect the process. A single incoming material excursion can negate hard-won fab yield improvements. Another key Supply Chain aspect that is often missed is the lag time component. The suppliers manufacture the materials weeks or months before they arrive in a fab which means that by the time a fab detects a material excursion, the supplier may have huge quantities of discrepant material on hand. Traditionally, we have relied on the purchasing specification to address these issues, but we have found countless times that material which meets specification can still fail in a product.

Suppliers collect a lot of data for the materials they produce but this data typically remains internal to the supplier or is only shared during technical meetings or quarterly trend reviews. Furthermore, the suppliers sometimes have limited data analysis resources and they lack the visibility into how small shifts can affect quality and yield.

In order to address the challenges listed above, Qorvo has leveraged the supplier data and established a ship-to-control methodology in partnership with the suppliers. This methodology includes upstream process control, metrology correlation, best/most complete definition of process windows, and fast data turns. By leveraging the supplier data and using ship-to-control, we have been able to achieve tighter control of the materials and reduce material-related yield loss.

In this paper, we will describe Qorvo's ship-to-control methodology and the results that are seen on our parametric trends and process control. The materials we focus on in this paper are GaAs Epi Wafers and Metals, but Qorvo also applies STC to other commodities including Chemicals and Silicon Wafers.

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METHODOLOGY

The supplier shares their process control data via FTP or 2-D barcode. We use Spotfire® Data Analytics to display the data and correlate it with or plot it against our product parametric data or process data. See Figure 1.

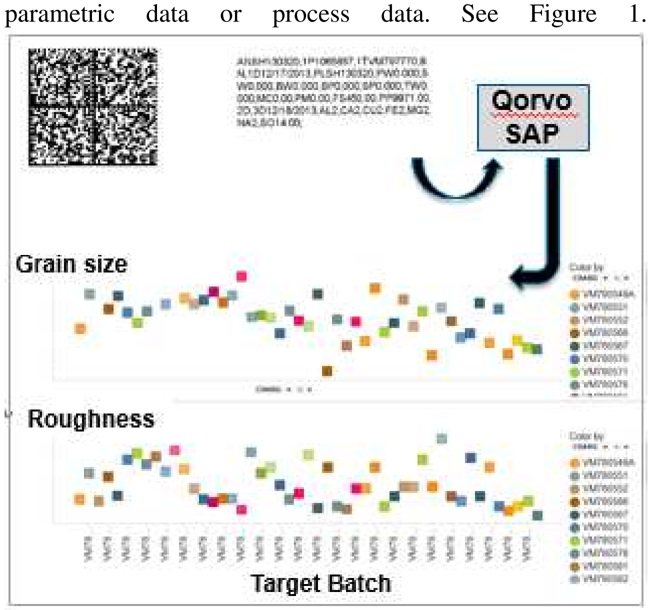


Figure 1: The Metal supplier provides certificate of analysis (COA) data into a 2D bar code. The receiving department scans the bar code and the data is uploaded to SAP® where it can be accessed by Spotfire® for display, correlations etc.

When sufficient data is available, we negotiate the ship-to-control limits with the supplier. Some STC limits are validated by correlation data (we know our process is affected beyond these limits) and some limits are purely statistical (we know material within these limits work, we do not know what would happen beyond). In the latter case, if the supplier faces a situation where material was produced beyond the limits, we evaluate the material to validate and we revise the STC limits accordingly.

The parameters, test methods, sampling and limits are documented in a supplier-specific STC spec. The spec captures all the learnings and is continuously edited as we continue to uncover new process corners, implement process changes, and design new products. The spec is published on the Proprietary Qorvo Spec Portal so that suppliers always have access to the latest revision.

RESULTS

1. Metals

In the case of metals, we implemented ship-to-control on the parameters in the Certificate of Analysis (COA) as a start. STC significantly increased the attention and the focus of the suppliers on the data, attention that may have been lacking if the data contained in the COA was never being scrutinized. In one case, the supplier became aware that the lab they were using was measuring the impurities incorrectly (See Figure 2). In another case, the supplier discovered that the sub-supplier had changed their measurement metrology from ICPMS to GDMS without notifying them. The new data reported was very different and required correlation and new calculated limits. Overall, implementing STC has really *engaged* our suppliers in maintaining and perfecting the control of the materials they are shipping to us and that make us successful.

Metals (similar to Epi wafers) present a high risk because a shift in the material may only be detected at electrical test, sometimes days after the metal deposition step and at which point hundreds of wafers may have been processed with the discrepant metal. Furthermore, metals purchasing specs are generally too sparse and the limits are loose. When a metal process is developed, some parameters may be carefully studied like composition and grain size, but no one can afford to do process margin studies on all the characteristics of the metal. Therefore keeping the material in control around the original process of record is the best course of action to minimize issues. For some suppliers, implementing STC has really put an emphasis on Statistical Quality Control (SQC) and Statistical Process Control (SPC) that was not there before. Some suppliers do not have the resources to focus on SQC and SPC. Even though most have the capability, it is simply not a priority among all the other requirements of the business, including keeping costs low.

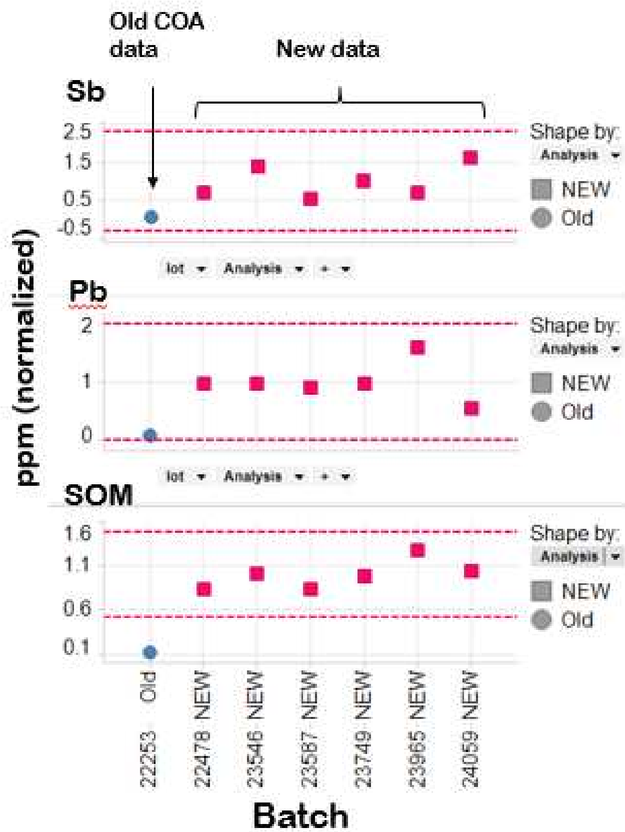


Figure 2: Antimony, lead and Sum of Metallics (SOM) in a tin material. The supplier historical COA (circle marker) was inconsistent and did not align with an independent analysis we had done on the material due to an excursion. The supplier engaged a different lab and started reporting data in alignment with the independent analysis (square markers). The dotted lines and +/- 3 sigma for the square datapoints.

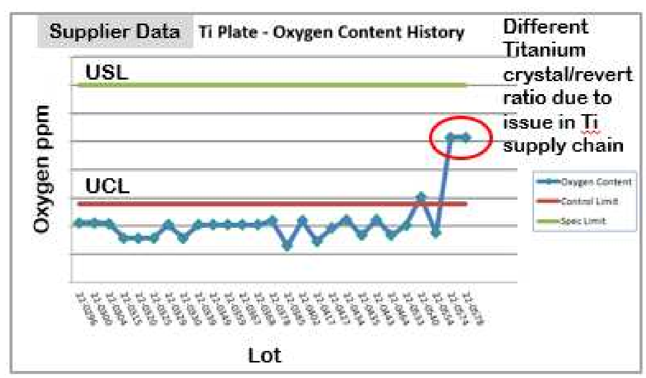


Figure 3: Oxygen (ppm) in Titanium target. The supplier caught the uptick as part of Ship to Control and found out that there had been a change in the Titanium powder supply chain. The Ti powder source had increased the ratio of revert/crytal Ti due to an issue with the Titanium sponge. The new ratio was considered qualified by the raw material supplier and the material in spec, therefore they had not notified our target supplier.

The suppliers also lack the visibility into the sensitivity of the fab process to changes. Implementing STC has proven very valuable in capturing changes and trends well inside the spec limits and addressing issues before installing the Material in the tool. An example is shown in Figure 3 where the supplier saw an uptick in Oxygen content in a Titanium target and flagged us about the Material. The material was evaluated under engineering before being released to production.

2. Epi wafers

Due to the highly technical and complex nature of the material, Epi suppliers collect a lot of data and are savvy in SQC and SPC. The Epi data had historically stayed internal to the suppliers but as we worked to implement ship-to-control, our suppliers willingly shared their control plan and the data they collect, which goes well beyond what is included in our purchasing specs. Getting access to the supplier data gave us the means to connect the supplier data to the device parametric data *in real-time* and we have been able to use the data to confirm the process windows. We *continuously* feed all this information upstream so the epi can be better controlled and targeted with each batch.

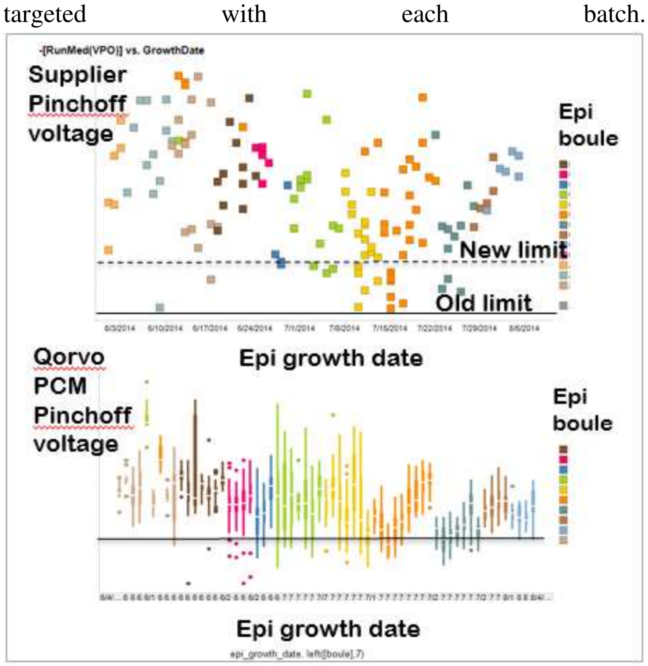


Figure 4: The supplier pinch off voltage (top) for one of our pHEMT epi showed a trend down but was still within our original ship to control spec. Qorvo device voltage (bottom) trended low and started failing the spec limit. We worked with the supplier to implement a new STC limit (dotted line, top) and eliminated the failures.

One of the first materials we addressed with this STC methodology was MBE pHEMT epi wafer production. We were in a time-critical transition to a new supplier which necessitated very fast learning cycles. By correlating the epi data to Qorvo product parametric data, we were able to quickly establish a STC specification. As we ramped production, some wafers started failing for low pinchoff voltage, which correlated to low pinchoff measured by the supplier and we quickly adjusted our STC limit to prevent future failures (Figure 4).

Similarly, in the beginning of the process exercise, some material showed failures at RF testing which correlated with R_{on}, which in turn correlated to variation in the aluminum percent of the Schottky device layer. We added aluminum calibration wafer photoluminescence wavelength standard deviation to the STC spec and we eliminated the failures (See Figure5).

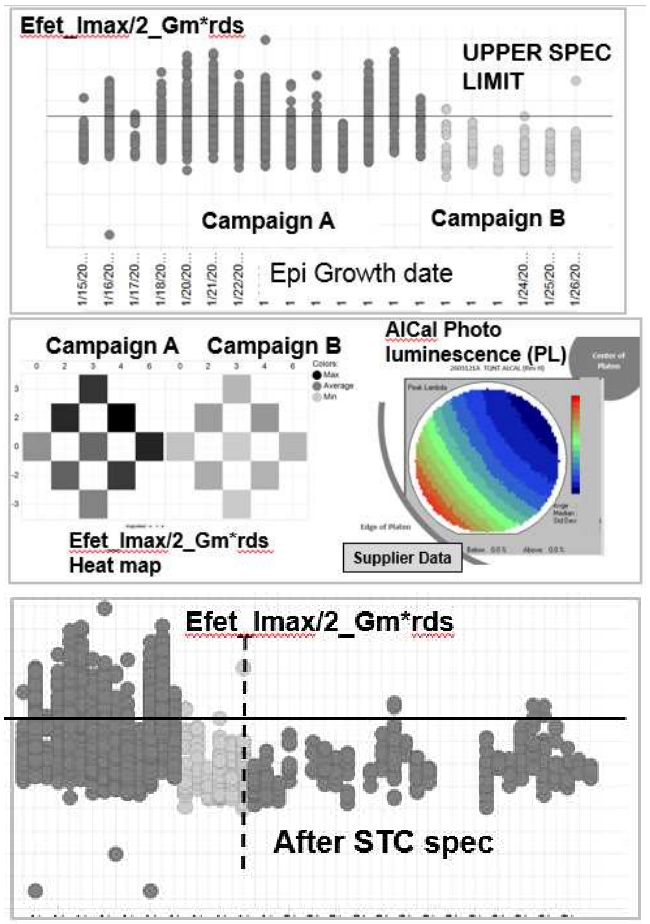
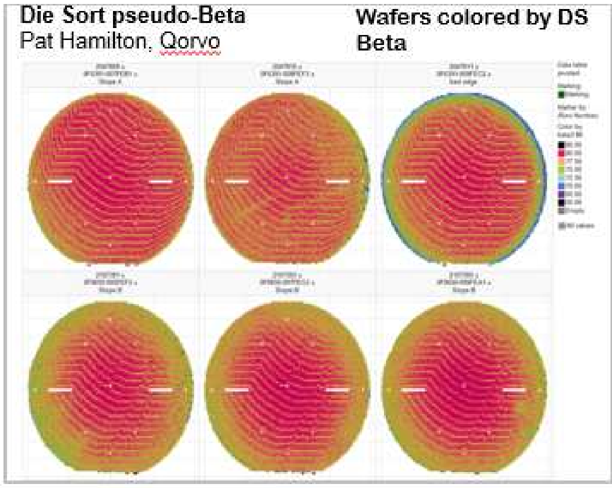


Figure 5: (Top to bottom) 1. Epi Campaign A was failing for an RF test parameter. 2. RF parameter Heat Map for Campaign A showed a strong Northeast to Southwest signature indicative of MBE reactor and similar to the map of Schottky Aluminum % variation across the wafer. 3. Al% Standard deviation Upper Control Limit was added to the STC spec and RF test failure was eliminated.



Supplier Data

Growth Date	06/09/2014	11/13/2014	11/14/2014	11/16/2014	11/18/2014	11/19/2014	11/20/2014
Run	8	6	5	6	1	2	7
Position	7	5	3	2	6	5	3
#1	>76	>76	>76	>76	>76	>76	>76
#2	>76	>76	>76	>76	>76	>76	>76
#3	>76	>76	>76	>76	>76	>76	>76
#4	>76	>76	>76	>76	>76	>76	>76
#5	>76	>76	>76	>76	>76	<76	>76
#6	>76	>76	>76	>76	>76	<76	<76
#7	>76	>76	>76	>76	>76	<76	<76
Average	XX	XX	XX	XX	XX	XX	XX
Variation	XX	XX	XX	XX	XX	XX	XX

Edge sites

These growth dates have edge site beta measuring at <76.

Parameter	Test condition	Freq.	LCL	Units
Beta@1KA/cm² MIN of 7 sites	Gummel plot, Large Area device, 7 sites	1/n days	76	

Added Beta MIN to STC spec

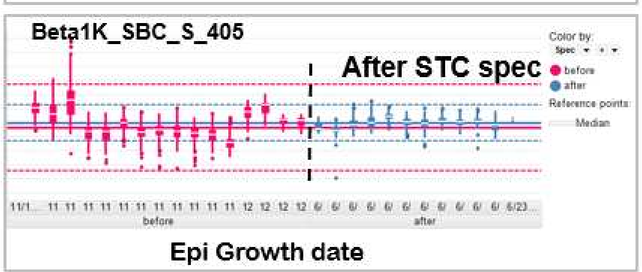


Figure 6: From top to bottom- 1.Yield engineering investigated yield fallout at final test due to low beta and found correlation to the wafer edge of particular epi runs. 2. The supplier collects data at various sites and was able to predict the low Beta. 3. Beta Range and Min was added to the STC spec. 4. The failure mode was eliminated.

Ship-to-control leverages the controls that the supplier has in place and uses these controls to maximize product quality. A particular Qorvo product requires a narrow window of HBT beta and we were seeing final test fallout due to low beta at the wafer edge. Our supplier actually measures beta at various sites across the wafer including the edge. We implemented a STC spec on the minimum beta and we were able to eliminate this failure mode (See Figure 6).

3. Continuous Improvement

Utilizing the supplier data has proven a major tool for continuous improvement. Every trend, every mismatch between batches or supplier tools is a learning opportunity. We can continuously observe how our product responds to changes. Is it sensitive or not to the change? What effect do we see? Is the change detrimental or beneficial? Having the STC data allows us to hone in on our correlations, better control the material upstream and sometimes actually improve our products performance. We continue to build STC into more materials and commodities to help ensure the highest quality and reliability for our customers.

CONCLUSION

The implementation of this ship-to-control methodology on key materials at Qorvo has reduced material related yield loss and significantly increased the speed of troubleshooting, learning, and continuous improvement. As products become more complex and performance requirements increase, incoming material control and optimization is paramount and STC is critical to support Qorvo's continued leadership.

ACKNOWLEDGEMENTS

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ACRONYMS

STC: Ship-to-control
SQC: Statistical Quality Control
SPC: Statistical Process Control
COA: Certificate of Analysis
PHEMT: Pseudomorphic High Electron Mobility Transistor
HBT: Heterojunction Bipolar Transistor
MBE: Molecular beam epitaxy
SOM: Sum of metallic
ICPMS: Inductively coupled plasma mass spectrometry
GDMS: Glow discharge mass spectrometry