Challenges of Short Lifecycle Commercial Products in Compound Semiconductor Manufacturing

Howard S. Witham, Ph.D.

TriQuint, Inc., Richardson, TX 75080-1324, **howard.witham@tqs.com**, 972-994-8213

ABSTRACT

With continuing expansion of RF content in the high volume commercial electronics market, compound semiconductor companies are challenged by the need to respond to very short consumer product lifecycles on the order of one year. The future winners will be those companies that can achieve fast new product development (NPD) cycle time and excellent cost and quality performance early in the manufacturing ramp. This is especially challenging for compound semiconductor wafer fabs that have traditionally had missions of high performance foundry and customization, when these factories with older equipment retool or create new commercial lines.

This paper will look at the impact of attaining early peak yield on cost, and how statistical control systems in the supply base, and very fast NPD cycle times for critical prototypes can help attain higher early yields. Also, factory automation as an enabler to traditional cost drivers such as zero excursions, yield enhancement, and direct labor productivity will be investigated.

INTRODUCTION

The TriQuint Texas factory, today located in the Dallas suburb of Richardson, traces its roots back to the Texas Instruments Defense Systems and Electronics Group in the early 1980's. The specialty of this operation has traditionally been high performance compound semiconductor RF products for the defense industry. With both internal and foundry designs, the 100mm GaAs/GaN line could be described as moderate volume, high mix, and highly customized. This line also runs a very high percentage volume of research and development wafers, while working closely with government agencies and defense industry partners. TriQuint acquired the Texas operation in 1998, merging its traditional commercial GaAs business with a new defense systems group.

In the mid 2000's, as the popularity of the smart phone began to grow, the TAM for RF content available to compound semiconductor companies also grew at better than 17% CAGR. While previous generation phones had $1 of RF content, current generation smart phones have as much as $10 [1]. Driven by 4G phones, the RF TAM is expected to continue to grow at 14% CAGR from 2012 to 2015 as shown in Figure 1. Like many companies supplying to the RF market, TriQuint had the need for capacity expansion in the commercial product space. The Texas fab, originally built for DRAM, had the necessary floor space and modern facilities for the company to expand its commercial GaAs and filter capacity. Two new 150mm lines were created under the same roof with a high volume, low mix commercial products mission in contrast to the highly customized 100mm line. The short lifecycles of commercial products placed a new challenge on the Texas operation.

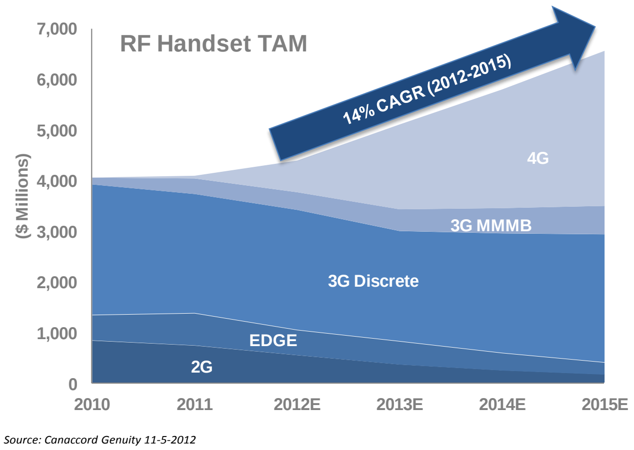

Figure 1: RF Handset TAM

SHORT COMMERCIAL PRODUCT LIFECYCLE

In contrast to defense products that can have lifecycles as long as 20 to 30 years, a smart phone typically has a lifecycle on the order of one year. Speed through the design NPD process is essential. For a commercial product ramp, integrated circuit demand often requires that 60% of the total product be built in the first two quarters, as shown for a typical lifecycle in Figure 2.

Production cycle times and yields must be very good from the outset to achieve excellent cost. Figure 3 shows a model of the cumulative margin difference during the lifecycle of a Bulk Acoustic Wave (BAW) filter product. This model is based on the difference between examples of slow and fast total yield learning curves. The margin difference is calculated as a function of the yield difference at a given point in time. The margin difference multiplied by the volume at that point in time is the volume weighted margin difference. The cumulative margin difference is the sum of the margin difference through the life of the product.

In the model one can see the cumulative margin difference between the slow and fast learning curves flattens

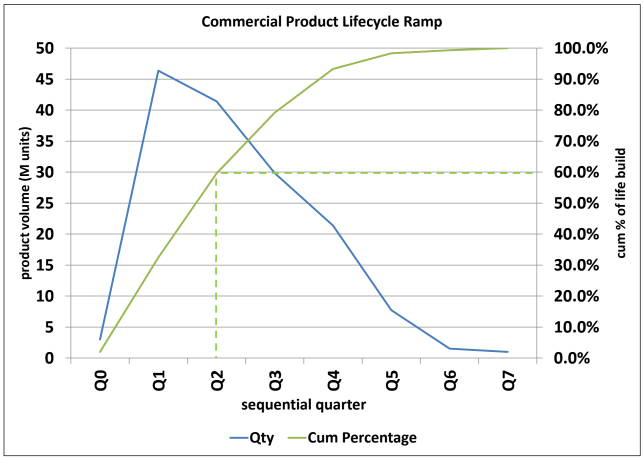

Figure 2: Commercial Product Lifecycle Ramp

out after eight months at 4.45%. This cumulative margin difference is pure profit to the bottom line. A product expecting revenue of $10M, $50M or $100M, through its short life time, would lose $0.45M, $2.25M, or $4.45M of profit respectively. If the factory can achieve the highest anticipated yield from the start, the asymptotic value of the cumulative margin difference is 7.2% to the slow learning curve. The impact to profit for the same anticipated revenue would then be $0.72M, $3.6M, or $7.2M respectively.

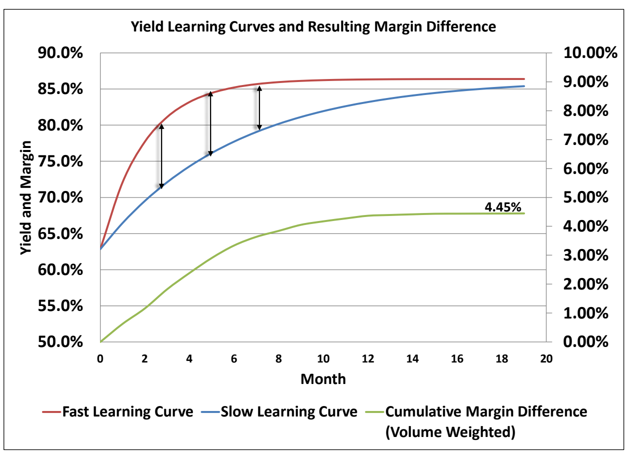

Figure 3: Yield Learning Curves and Cumulative Margin Difference

Challenges for the Fab

The short commercial product lifecycles put significant pressure on the wafer fab to produce great results early in the ramp. The fab must have excellent speed for NPD prototypes during development and also for fast engineering learning cycles when working to improve yields. Factory automation helps with the speed of the line and fast NPD turns. It is also key for preventing zero excursions through Advance Process Control (APC), improving direct labor productivity and scrap, facilitating yield improvements through inline Automated Optical Inspection (AOI), and through statistical process control (SPC) for maintaining high levels of incoming quality with suppliers.

The need for fast NPD turns can often require a cycle time of two weeks or less, or a cycle time of < 1 day per mask level. Figure 4 shows the components that make up an 11.9 and 12.9 day NPD cycle time on two BAW products with approximately 19 equivalent mask levels. Previous efforts on the same line had produced results > 1 day per mask level.

Many key actions helped achieve this result. Starting with rigid automated design rule checks and clean input files, the process flow is required to have as little non-standard processing as possible. Process recipes and test programs must be ready prior to lot start. Multi-circuit masks can help investigate several designs on one fab turn. At those steps where non-standard processing is necessary, 24 x 7 engineering coverage is required. Frequently updated schedules alert engineering and production personnel to when material will arrive at their step. Tools are kept open so there is little queue time. Many non-value added steps, such as visual inspections, measurements, and inline probes are skipped. Final probe steps to evaluate results can use a skip die or interpolated approach. Reduced lot sizes can also have a big impact. In this case, a standard 24 wafer lot was reduced to 12. What is also clear in Figure 4 is that there is still queue time that leaves room for continuous improvement, and the theoretical process time can always be challenged.

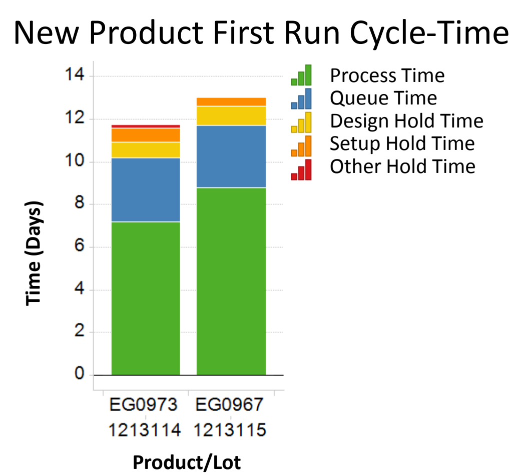

Figure 4: New Product First Run Cycle Time

APC is not a new concept, but is being deployed in many forms and locations on the TriQuint Texas lines to help improve yields and prevent quality excursions. Figure 5 shows an example with in situ RGA data from a PVD aluminum deposition process. Ideally, a metal PVD process should have very high vacuum integrity and only show a strong signal from the intended argon sputtering gas. Background levels of nitrogen, oxygen, or hydrogen should be very low. If they are not, it is likely an indication of a vacuum leak or contamination in the argon sputtering gas.

In this case, the nitrogen peak was determined to be contamination of the argon gas from a maintenance event. The contamination was later confirmed with sheet resistance measurements on the aluminum film. The traditional sheet resistance monitor wafer or sheet resistance measurement at a probe step does not occur in real time, and leaves the operation susceptible to an excursion. The APC RGA approach can detect a leak or contamination in real time and automatically shut a processing tool down, scrapping one or no wafers. This is important for processes like BAW that are very dependent on thin film quality.

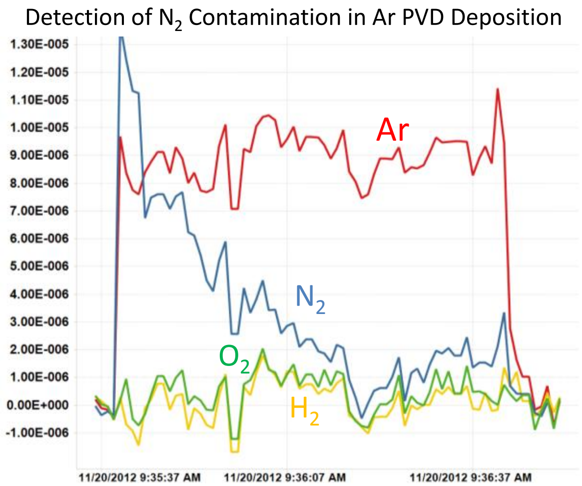

Figure 5: Advanced Process Control

Figures 6 and 7 show the impact of automation on direct labor productivity and direct labor scrap rate. Most tools on the commercial 150mm BAW line have automated wafer to wafer handling and SECS/GEM recipe downloading. In contrast and because of the older vintage of tools, the 100mm GaAs/GaN line has mostly manual wafer handling, manual recipe select, and wafer lot sizes that are typically 4 times smaller. The same engineering and manufacturing management run both lines with similar methodologies. Through the short lifetime of the commercial BAW line and as it has grown in capacity, the impact of the larger lot sizes and automation on productivity and direct labor error rate is clear in comparison to the more manual 100mm GaAs/GaN line. Every automation effort for the 100mm line is being considered, but opportunities are more limited.

Defense industry requirements drive tough final visual inspection criteria for the TriQuint 100mm GaAs/GaN line. In a similar fashion an AOI final visual screen was implemented on the 150mm BAW line. In the infancy of this line, AOI screens could take out up to 10% of the die, in addition to electrical yields. A two year battle against defectivity ensued. Originally the line was set up with AOI

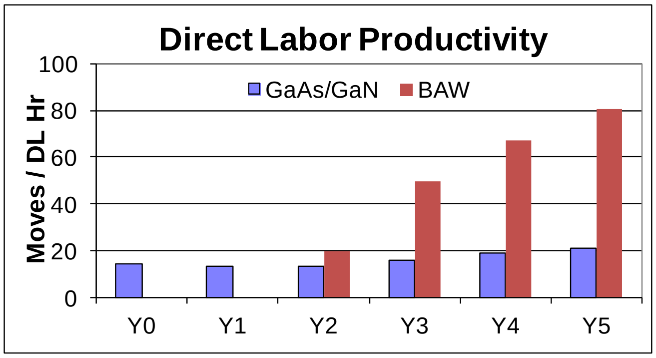

Figure 6: Impact of Automation on Direct Labor Productivity

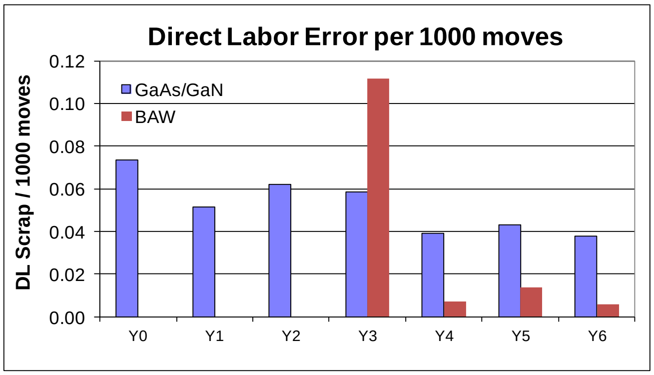

Figure 7: Impact of Automation on Direct Labor Scrap

only at the end of the line as a screen. While it was not a novel concept, AOI sampling was implemented at key steps within the processing line to try to determine a solution for the key problems impacting visual yields. Through learning from the inline AOI data, many issues were fixed or improved including SU8 coat, bake and alignment (SU8 is an epoxy based photoresist used at the wafer level to build the cavity housing for the filter die). Other key actions taken as a result of inline AOI learning include bond pad residue reduction and improvements to the UBM lift off process.

Figure 8 shows an 8% improvement in AOI yield over a 16 month period. These improvements, mostly as a direct result of inline AOI, can equate to over $1M in scrap per quarter.

Many fabs in the industry have experienced problems with incoming chemicals, gases, or epitaxial wafers that were considered in spec but still caused a major quality excursion. The push for zero defects, zero excursions, and high yield early in the commercial product ramp, necessitates that tighter controls be implemented in the supply chain for incoming quality.

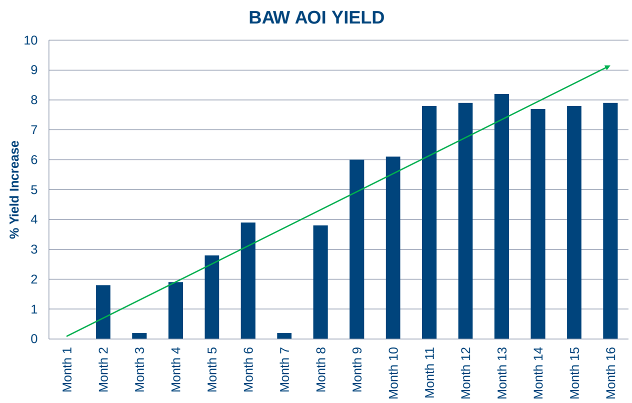

Figure 8: BAW Optical Yield Improvement through AOI

Figure 9 shows the impact of incoming quality control on a wafer level electrical parameter, before and after SPC was implemented with the epitaxial supplier. After SPC implementation, the supplier performance became more consistent. However at a later time, while in spec at the supplier, the incoming material pushed the fab out of spec. Quickly the process was retargeted at the supplier and the wafer level electrical parameter moved back into spec. These types of controls and correlations between SPC at the supplier and fab level will help to quickly spot problems and prevent major excursions. In addition to preventing excursions, it also has the possibility of improving prime electrical performance at the wafer level early in the product ramp.

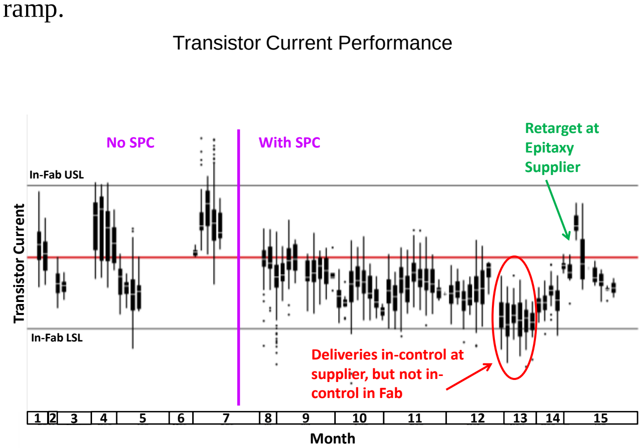

Figure 9: Driving Incoming Quality with Supplier SPC

CONCLUSION

Commercial electronic products with short lifecycles, on the order of one year, present many challenges to compound semiconductor manufacturers. The need for fast NPD cycle times of < 1 day per mask level are necessary. This can be accomplished with clean design input files, streamlining the process flow, limiting the non-value added steps, reducing the lot size, and providing around the clock engineering support. It has also been shown that fast engineering turns can have a dramatic impact on yields and financial performance when greater than 60% of the product for one generation of smart phone will be built in the first two quarters of the ramp.

Short product lifecycles presented a unique challenge to the TriQuint Texas facility when it started to manufacture parts for the commercial smart phone market in the late 2000's. The implementation and continuous expansion of factory automation on the new commercial lines was very important for improving yields and quality. This was done with a high level of automated wafer handling and recipe control that improved direct labor productivity and error. In addition, APC was implemented in key processes to help improve yields and prevent quality excursions, but the journey on APC is not complete and will continue into the future. An example was also presented on the importance of AOI. Using AOI, not only as a screen at the end of the line but as an inline tool, can help improve die yields.

As the commercial smart phone market continues to advance and its supply chain works to keep pace, it is certain that compound semiconductor companies will need to continue to improve line speed, factory automation, and supply chain control to achieve financial success.

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REFERENCES

[1] David J. Aldrich, *Semiconductor Innovation: Enabling Mobile Connectivity*, CS MANTECH Conference, April 23rd – 26th, 2012, Boston, Massachusetts, USA

ACRONYMS

AOI: Automated Optical Inspection
APC: Advanced Process Control
BAW: Bulk Acoustic Wave
CAGR: Compound Annual Growth Rate
DRAM: Dynamic Random Access Memory
MMMB: Multimode Multiband
NPD: New Product Development
PVD: Physical Vapor Deposition
RGA: Residual Gas Analyzer
SECS/GEM: SEMI Equipment Communications Standard/Generic Equipment Model
SPC: Statistical Process Control
TAM: Total Available Market
UBM: Under Bump Metal