Addressing Cycle Time to Accelerate Yield Improvement and Improve Output

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Abstract

Cycle time is the superordinate metric of manufacturing that measures directly or indirectly every aspect of the health of operations from the complexity of the process, effectiveness of planning, engineering, maintenance and manufacturing. To drive the metric towards world class manufacturing levels, companies must examine and touch on every aspect of these operations. This paper will discuss how cutting the cycle time in half led to cutting yield losses in half in a fab. It will detail the methodologies that were used.

INTRODUCTION

Following a major scrap event, a semiconductor company collaborated with the MAX Group to help guide its wafer fab through a rapid recovery process and to position it for growth by ensuring best practices were being deployed in the manufacturing operations. MAX worked closely with the manufacturing team over the course of one year during which the factory realized a significant improvement in performance. At the core of this was a concentrated effort to accelerate the line, to cut the cycle time dramatically, improve yield and ramp output.

Fab cycle time directly affects what is known as the "Time to Detect" and the "Cycles of Learning" of a factory. They go hand in hand: the combination of being slow to detect excursions and then taking twice as long to test and implement engineering solutions can put the fab at a distinct competitive disadvantage. When yields are poor, cycle time is often contributing to the problem.

This paper details the methodologies employed to bring about a dramatic turnaround in performance. In addition, it presents why this is important to CS fabs with benchmark data.

THE IMPROVEMENT REALIZIED

Figure 1, 2, & 3 show the improvement realized. In these charts the baseline period consists of the previous 12 months performance data. Percentage improvement was used to obscure the actual numbers at the request of the customer. Figure 1, 2, and 3 show remarkable results. Wip and cycle time were cut nearly in half, output increased and yields improved substantially. The key to speeding up the line was to systematically lower the WIP. The key to improving yield was to improve the cycle time. As the line sped up, two well-known principles came into play: "Time to Detect" and "Cycles of Learning".

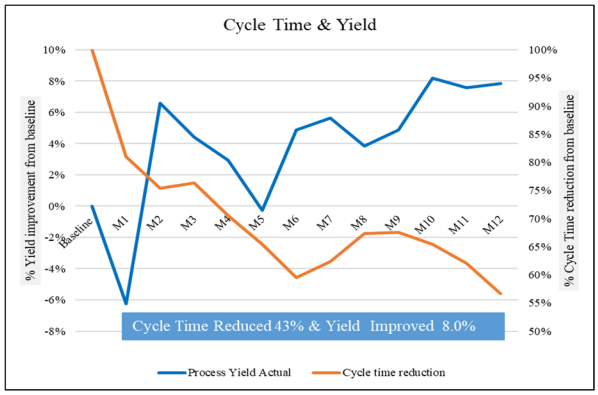

Fig. 1. As cycle time was reduced, yield improved.

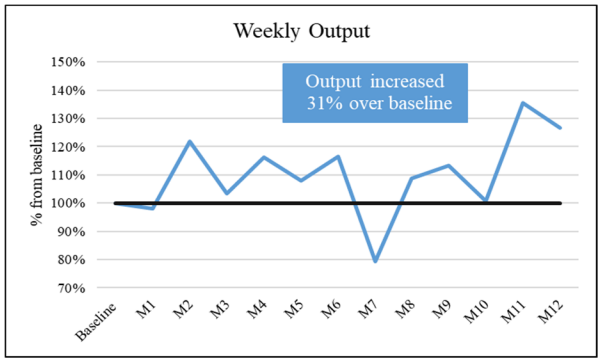

Fig. 2. Output was increased through the year.

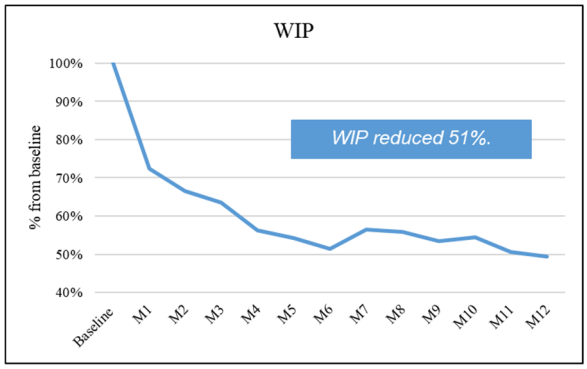

Fig. 3. WIP was cut in half from the baseline.

TIME TO DETECT

Fabs rely on a variety of techniques to control processes, tools and quality, such as: vendor quality management, metrology and inspection, SPC and APC (advanced process control), and FDC (fault detection and classification). Yet with all of this, semiconductor fabs continue to remain vulnerable to unexpected changes that impact product quality. The gap between the step that contributes the defect and the point of detection often entails many steps of manufacturing. In the worst case, it can stretch from defects in starting material that can only be detected in final electrical test. The "time to detect" a problem is critical in yield management. Sporadic problems will emerge and even with the best systems a fab can be vulnerable. Shortening the feedback loop by keeping cycle times to a minimum is the best defense. With fast cycle time you discover problems quicker and have less material at risk.

CYCLES OF LEARNING

Factories learn, make improvements, and realize gains as inventory turns over. Each turn of the inventory completes a "cycle of learning". For example; a factory that has cycle time of 17.3 weeks will see three "cycles of learning" in a year. With the cycle time cut in half to 8.7 weeks, the "cycles of learning" doubles to six cycles per year. By cutting the cycle time in half, the organization was improving at twice the speed that it was with the slower cycle time.

DEFINING THE IMPROVEMENT ROADMAP - STUDY PHASE

MAX has a very structured approach to study and quickly diagnoses the health of a fab, its strengths, and weaknesses, for the internal management team. It is a process called Overall Resource Effectiveness ™. The ORE™ is a deep-learning process that includes intensive a multi-observational study of the complex interactions of process tools, people, and WIP flow in the factory. It is targeted at identifying and quantifying the improvement opportunities.

During the assessment phase, interviews are conducted with all levels of people in the factory. A number of "deep dives" are carried out involving both detailed data analysis and direct observations to explore a topic in full. By the seventh week on site, the observations, discussions, and data all coalesced into a clear picture of what the problems were and what would need to be done. These findings, along with the roadmap for improvement, was presented to the fab team. The hard data captured through the ORE™ sampling process brings lots of credibility to the findings.

Every factory is different. The variables of the factory mission, evolution, scale, structure, location, people, and culture drive differences in approaches tackling similar problems. However, there are common approaches that best-in-class factories use. The fundamentals of world-class manufacturing do not change. Identifying the gaps through a deep-learning phase and then working to close these gaps becomes the implementation phase. Since every factory differs, the starting points and priorities on what to address and, in which sequence, will differ as well.

From the study, it was determined that the fab's cycle time, as measured in DPML (days per mask layer) and X-factor, was far from industry benchmarks. DMPL is the total cycle time divided by the number of mask layers in the process. X-factor is the actual cycle time divided by the theoretical process time.

Cycle time is the superordinate metric of manufacturing effectiveness, the key measure of the health of the manufacturing ecosystem. With the fab's cycle time being far from benchmark, it was clear that if it was brought under control, yields and output would improve.

In queueing theory, Little's law defines a simple formula that applied in manufacturing shows the mathematical relationship of WIP, cycle time and throughput. Little's law leads to the following conclusion: to shorten cycle time, a fab must lower the WIP or increase the throughput. Most often a combination of the two are addressed.

The challenges identified in this fab fit into the following broad categories; process and equipment management; shop floor and manufacturing management, and business processes.

IMPLEMENTATION PHASE - BUSINESS PROCESSES

Business processes are the routine, structured activities, tasks, or policies that a company uses to achieve certain goals required in the operation of a company. A number of important business processes were missing or needed to be improved.

1.) S&OP (Sales and Operating Plan): A process to ensure alignment within the company on demands, wafer starts, and expected output was created. Previously, the fab was operating independently leading to misalignment.

2.) Understanding the fab operating curve; the interrelationship of the factors of production, basic cycle time formulas from operations research, and their application in manufacturing models, was key in the development of the roadmap for improvement. A fab manufacturing model was developed for setting integrated targets for activity for each planning period over an 18-month horizon. From this, an improvement plan

was established to draw down inventory and to gradually increase daily moves while achieving expected output.

IMPLEMENTATION PHASE - SHOP FLOOR AND MANUFACTURING MANAGMENT IMPROVEMENTS

A structured approach to manage the manufacturing line was needed to achieve optimal cycle time and throughput. The right information needed to be available from the reporting systems, with proper and timely responses to issues in the factory. Many of the factory floor supervisory and managerial practices needed improvement. Much of this work came directly from MAX's SuperKit™, which was designed to define how to best run the day-to-day operations in a factory. Some of the elements addressed included the following:

1) Defined and guided a daily production meeting.
2) Developed a KPI dashboard to track the right metrics for the line.
3) Closed a gap between the shifts at shift change that resulted in tools going idle.
4) Worked with supervisors to monitor the line in a structured way. Knowing when and how to respond and escalate manufacturing problems in the most effective way.
5) Implemented MAX's Fab-Jam™ (go to the Gemba) where managers and engineers spend a full day working the same shift as the operators and technicians supporting them, observing firsthand the issues they encounter.

The above solutions were a natural outcome of using the SuperKit™ process while other operational challenges were also addressed. The fab's tool layout greatly affected productivity and cycle time. We found widespread issues in how tools were located within the fab and many cases of inadequate space to store WIP convenient to the tools. This confounded WIP movement and led to a very large centralized WIP room. Factories should be designed so lots can move from tool to tool in a direct manner avoiding unnecessary travel. In this case, lots were being sent to the WIP room where they then waited to be dispatched to a next step. Operators would walk to the WIP room to deliver completed lots and to pull lots. This resulted in unnecessary lot travel and lost productivity. It was calculated that more than 30% of the travel per lot was wasteful due to the fab layout.

As WIP levels were reduced, the challenge of how to move lots from tool to tool efficiently was magnified. Typically, there is no magical solution for this as relocating tools in a fab is very expensive and totally disrupts normal production. MAX worked with the fab on a series of incremental, local improvements. Rather than having operators hunting for their next lot, the team implemented a "bus route" to have WIP delivered closer to tools so the operator running the process tools would remain on task. Where possible, WIP racks were placed close to tools and the lot dispatching system was adjusted to move lots directly to the next tool when a clear path was defined. As the project progressed, relocation of some of the tools to mitigate risks and further improving cycle time was identified as necessary.

IMPLEMENTATION PHASE - PROCESS AND EQUIPMENT MANAGEMENT IMPROVEMENTS

Organizational structure can differ from factory to factory based on the maturity of manufacturing and the mission of the factory. MAX quickly recognized that the fab process and equipment organizations' structures inhibited the fab from being successful. Process Engineers were consumed with daily triage and "fire-fights" to keep the line running, with very little time spent on improving processes. Process Section Managers were supervising Equipment Engineers who were also directed towards the daily tactical issues and spending little, if any, time on developing improvement roadmaps. Equipment Maintenance Technicians reporting structure was separate, with Shift Managers reporting to the Process Equipment Director who was able to spend little time to provide the day-to-day leadership required. The lack of alignment between Equipment Maintenance and Equipment Engineering led to numerous disconnects.

We embarked on implementing changes so that the Equipment Engineering function would be structured under one leader. This was another step towards shifting the focus of traditional engineering work back towards improvement-oriented engineering work.

We offer a very structured approach to how companies should approach maintenance practices called MAX Precision Maintenance™ (MPM™). It encompasses a set of metrics that fully quantifies the precision of maintenance activities along with techniques, expectations and practices for a maintenance organization to drive those metrics to achieve gains in performance. MPM™ is as much a cultural change as it is a change in methodologies. Nevertheless, three focus area teams were formed to facilitate a faster introduction and use of MPM™ concepts. Each of the three focus teams demonstrated improvement in the trends.

RESULTS

Figure 3 shows that the WIP was reduced. At first dramatically, but then more gradually. Wafer starts were tightly controlled to pull down the WIP. This required a "leap of faith" by the fab team as they believed they needed more inventory to achieve the output targets. Figure 2 shows that the factory was able to achieve output well above the historical levels. Figure 1 shows the correlation between the cycle time and yields. Yields continued to rise, reaching industry benchmarks within two months after the close of the project. Dramatic improvements were realized through understanding the principles of cycle time, developing a cycle time improvement roadmap, and methodically implementing it. The results improved on-

time deliveries and, most importantly, yield which also provided better output and improved customer quality.

CONCLUSIONS AND IMPLICATIONS FOR COMPOUND SEMICONDUCTOR FABS

Fast cycle time is an enabler of high yield. The methodologies to optimize cycle time performance are universal and have direct applicability to semiconductor fabs regardless of the starting material. Compound semiconductor fabs, however, do face unique challenges when compared to silicon-based semiconductor fabs.

Benchmark data was collected by MAX between 2013 and 2017 from 56 fabs. Of those, 17 fabs were operating at the 150mm node of which four were CS fabs. All 17 fabs face the same issue operating with a generation of tools originally deployed in the 1980's. Although the CS fabs in the study are limited in number, there are some useful conclusions that can be drawn.

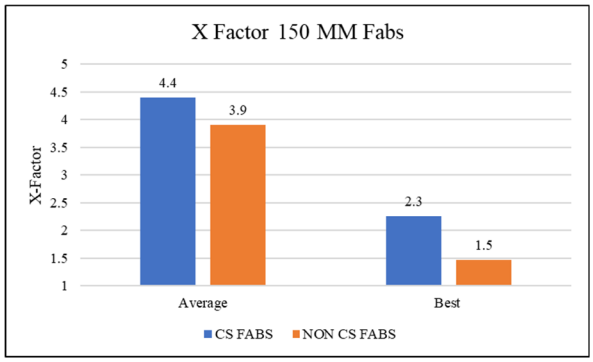

Fig. 4. X factor in 150 MM fabs.

Figure 4 shows that compound semiconductor fabs perform poorly when compared to non-CS fabs on cycle time. The gap may not look significant; but we know from experience that as X factor moves above 4.0, a fab is in a precarious position of approaching the vertical asymptote of the operating curve. A fab can quickly lose control of cycle time operating at this level.

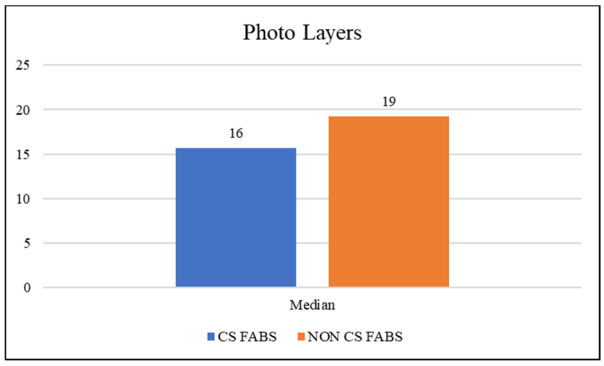

Fig. 5. Photo Layers in 150MM fabs.

Figure 5 shows the number of photo layers as a comparison. This can be used a proxy for the number of steps in manufacturing and can be extrapolated to suggest that the number of tools that a CS factory might need to ship an increment of production is less than a non-CS fab.

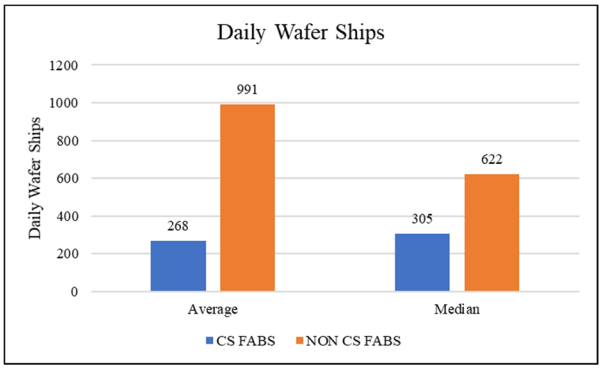

Fig. 6. Daily wafer ships from CS fabs and non-CS fabs.

Figure 6 shows the volume of wafers being shipped daily from fabs in the study. CS fab output is 1/3 to 1/2 the volume of a non-CS fab. When taken with the conclusions from figure 5, CS fabs are significantly smaller in scale. In small factories, capacity is concentrated on a limited tool base. There are more cases of "one of a kind", or "two of a kind" tool sets to support the capacity.

All things being equal, this means CS fabs face a more difficult challenge, but it presents a competitive opportunity for best-in-class CS manufacturers who can master cycle time management. Cycle time and yield are directly correlated. Time to detect and cycles of learning are hugely important in factories that are evolving and seeking benchmark results.

ACKNOWLEDGEMENTS

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ACRONYMS

APC: advanced process control
CS: compound semiconductor
DPML: days per mask layer
FDC: fault detection and classification
MAX: MAX International Engineering Group
SPC: statistical process control
WIP: work in progress
X-factor: ratio of actual cycle time/theoretical cycle time

MAX trademark business process nomenclature:
ORE™: overall resource effectivenes
MPM™: MAX precision maintence.
Fab-Jam™:
SuperKit™: