

Growing Scope
of 200mm Applications
Drives Advances in MEMS
Process Technologies

Demand for
200mm Tools
Outstrips Supply

China:
Investment Fever
Kicks IC Industry
Into High Gear

NANOCHIP

FAB
SOLUTIONS

Solutions for Factory and Equipment Efficiency



Still evolving: 200mm

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ABOUT THE COVER:

Just as the chambered nautilus
creates a larger shell for itself as it
grows, 200mm equipment continues
to evolve—and thrive—in the era of
mobility and the Internet of Things.

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BACK TO THE FUTURE: BUILDING THE LATEST TECHNOLOGY WITH LEGACY TOOLS



CHARLIE PAPPIS

GROUP VICE PRESIDENT
AND GENERAL MANAGER,
APPLIED GLOBAL SERVICES

A Letter from Charlie Pappis

When it comes to the fast-paced world of technology, we tend to assume that whatever's "the latest" is also "the greatest." Just look at the long lines that form outside your local Apple store every time a new version of the iPhone is released.

That's why the unprecedented surge in demand for 200mm legacy tools, largely driven by mobility innovations—including smartphones and the Internet of Things (IoT)—presents such an interesting challenge for the semiconductor industry. Although FinFETs, 3D NAND and other leading-edge device designs continue to push the IC technology roadmap, the fact is more than 75% of the ICs in the latest iPhone 6 Plus were manufactured on trailing-edge 150mm and 200mm equipment—much of it first delivered back in the 1980s.

These legacy tools are vital to delivering a steady stream of cost-sensitive "More-than-Moore" devices. Fabricated with non-leading edge die, these devices are produced in fabs that must continuously evolve to operate flexibly and with peak yield and maximized output.

This is a high-value problem that Applied Materials understands very well, and is committed to helping our customers address. In this issue of *Nanochip* you'll learn how Applied Materials is continuing to invest in manufacturing, technology and service offerings for 200mm platforms through our R&D facility in Xi'an, China, our 200mm lab in Singapore, our manufacturing operation in Austin, Texas, and other satellite operations in Gloucester, Massachusetts, Kalispell, Montana, and Tel Aviv, Israel.

A great example is the new Applied Vita controller, introduced last fall. Many 200mm systems have controllers that were designed decades ago and haven't been updated since. The Vita controller includes a much more powerful processor, flash memory and other features that can bring 200mm Applied Endura and Centura systems up to modern levels of performance and process control. When combined with our growing portfolio of advanced, technology-enabled service and consulting options, which we discuss in this issue, customers can increase output and improve 200mm device performance and yield.

A tangible example of our new outcome-based service programs is a case study describing how a foundry with Applied Centura tools engaged our FabVantage Consulting Group with a goal to cut scrap rates by 50%. The Applied consultants ultimately exceeded the customer's target, with recommendations and services which, when implemented, reduced wafer scrap to <0.2% and spending on certain parts by 4x.

Also detailed in this issue is the interesting strategy of Silicon Labs, a fast-growing, fabless supplier of devices targeting IoT applications, along with a compelling inside view of China's efforts to become an IC powerhouse. By leveraging government seed money and matching investments that could total US \$170 billion over the next 5 to 10 years, China hopes to emerge as a major new player in chip manufacturing.

Finally, we salute the 10th anniversary of *Nanochip Fab Solutions* with a look back at how much our industry has changed over the past decade. But what hasn't changed, and what I hope you take away from these pages, is that Applied Materials is here for you. Whether you're trying to optimize a legacy 200mm system, move to a new technology node on a state-of-the-art 300mm system, increase output, or reduce total costs, we can help you achieve your goals. Define the performance and the results you want, and we'll deliver the technology, service and support to get you there.



GROWING SCOPE OF 200MM APPLICATIONS DRIVES ADVANCES IN MEMS PROCESS TECHNOLOGIES

BY
MIKE ROSA,
PHD

As we all know, the 200mm wafer fabrication equipment (WFE) market is steadily shrinking and will be relegated to history in the not-too-distant future. After all, shipments of 300mm WFE have outpaced those of 200mm platforms since 2004-05 and now the industry is even contemplating 450mm platforms. In 2014, the 200mm WFE market was approximately \$1.5B (down from \$1.6B in 2013 with 4% year-over-year decrease^[1]). Cost efficiencies offered by the 300mm toolsets for the production of advanced memory and microprocessor devices have made it increasingly difficult to justify continued 200mm operation—right?

Interestingly, evidence suggests that these might be unduly pessimistic conclusions, similar to the misrepresentation that prompted Mark Twain to comment, “The report of my death was an exaggeration.” Even with the transition to 300mm wafers, fabs running 200mm wafers have continued to fabricate specialty memories; image sensors; micro-controller units (MCUs); analog products; motion, audio, and radio-frequency (RF) communication devices embodying MEMS; and discrete passive components such as resistors, capacitors, antennas, filters and switches.

Production of such devices makes good economic sense in fully depreciated 200mm fabs, including those formerly used for making devices now produced on 300mm wafers;^[2] furthermore, new market forces are re-energizing the 200mm equipment scene. Leveraging its core capabilities in precision materials engineering, Applied Materials is addressing the new challenges accompanying these rapidly growing market segments through sustained investment in R&D to expand the capabilities of its 200mm systems.

The drive to reduce chip costs was the leading factor in the transition to 300mm wafers,

which can accommodate more than twice as many dies as 200mm wafers. By 2013, 300mm wafers represented approximately 57% of overall semiconductor capacity, with IC Insights forecasting a rise to 64% in 2018.^[3] Production on 300mm wafers is predominantly in high-volume commodity chips, including DRAM, flash memory, and microprocessors. Foundries and IDMs favor them to best amortize their manufacturing costs per die. However, 300mm systems are also used for some production of image sensors, power management devices, and complex logic and micro-component ICs with large die sizes.

The automotive industry was among the first users of the devices fabricated on 200mm wafers and has been steadily expanding its use of sensors for improving vehicle efficiencies and safety. Similarly, industrial and medical applications have contributed to this market. However, the advent of wireless and motion-tracking technologies in consumer electronics has been the major stimulus for growth in applications produced on 200mm platforms. Sold in the hundreds of millions per year, first the iPhone and then the proliferation of other smartphones, tablet PCs, and related digital devices that

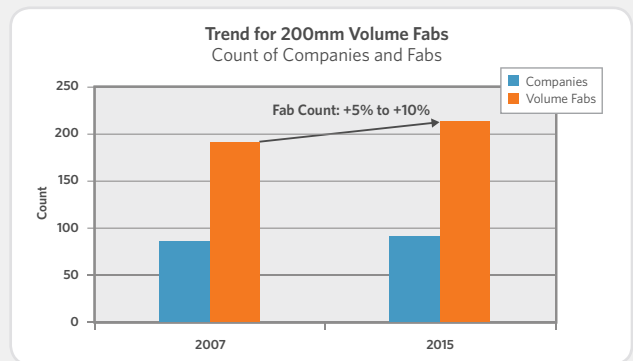


Figure 1. Production on 200mm tools is making small but steady gains.^[6]

followed spurred adoption of “More-than-Moore” devices. These comprise micro-scale, systems-in-package or system-on-chip devices, integrating processing power with sensors, RF communication, and a range of other functionalities. They can be fabricated using die with feature sizes greater than 1µm and profitably produced on 200mm systems.

Although ~5% of the total WFE market in 2014,^[1] 200mm applications are steadily multiplying (see figure 1). In 2014, fab investments by leading foundries and IDMs resulted in a 45% increase in spending for secondary 200mm equipment.^[4] Foundries account for two-thirds of this increase, responding to expanding demand for MCUs for automotive devices, consumer

electronics, power management applications, and emerging IoT-related MEMS and sensors.^[5]

KEY 200MM MARKET SEGMENTS

The automotive industry and consumer electronics sectors have been responsible for most of the 200mm production since before the 2008-09 industry downturn (see figure 2). Since the early 2000s, cars produced in the U.S. have been equipped with devices like tire pressure sensors that send data to the vehicles’ central computers. The average new car now contains 60 microprocessors; electronics for such functions as advanced driver assistance, heating and air conditioning, and rear-view cameras account for 40% of a car’s cost.^[6] According to Gartner, sensors will represent 31.3%

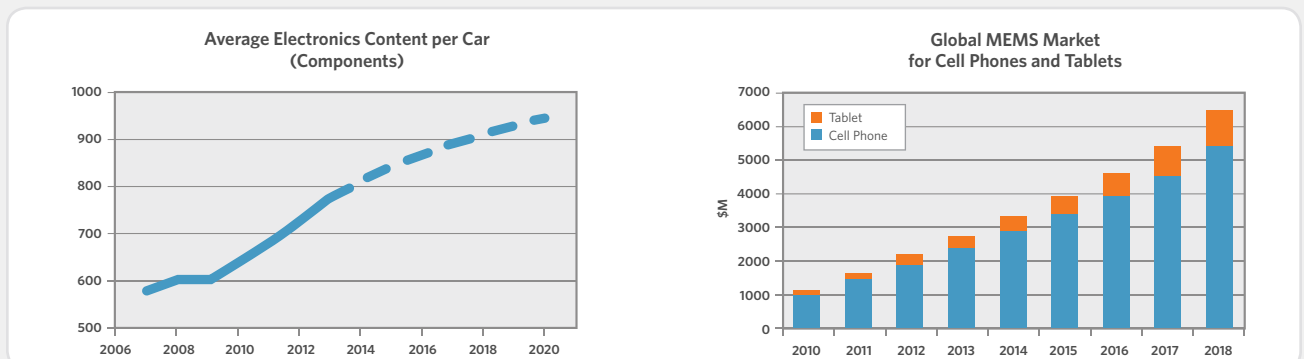


Figure 2. The automotive and consumer electronics industries are the most significant drivers of resurgent 200mm production.^[8,9]

GROWING SCOPE OF 200MM APPLICATIONS DRIVES ADVANCES IN MEMS PROCESS TECHNOLOGIES

of all IoT-enabled automotive semiconductors in 2020, with automotive safety applications the fastest growing segment for image sensors. Automotive applications will also be the biggest consumer of inertial/motion sensors (43%).

The automotive MEMS sensor market is expected to grow at a CAGR of 4.7% from 2014 to 2020 and become a \$3.6B market.^[7]

The consumer electronics story is epitomized by the global explosion in the use of digital cameras, iPods, smartphones, and tablets over the past 5 years. The value of MEMS produced for cell phones and tablets alone grew by \$500M in 2012.^[10] “Wearables” are now adding to the growth of this sector. These miniature electronic devices—such as the Nike+ system for tracking time, distance, pace, and calories through a sensor in the shoe, or the Apple Watch that integrates timekeeping and calendar information with address book, communication, and Internet capabilities as well as several activity monitoring functions—are driving exponential proliferation in sensor applications.

A new phase in interconnectivity will be fueled by the emerging IoT, which is predicted to link wearables, consumer devices, home automation, appliances,

healthcare/medical, retail/marketing, transportation, and everything in between over the next decade. Analysts predict that five years from now, IoT-enabled sensors will be a \$10 billion industry.^[11] This new development is reinforcing demands for economical production of cheaper, smaller, more capable, and more power-efficient devices—for which legacy or enhanced 200mm toolsets offer optimal solutions.

DELIVERING MORE THAN MOORE

MEMS are among the More-than-Moore devices rejuvenating 200mm production. However, manufacturing them poses challenges from material- or process requirements not encountered in traditional semiconductor fabrication.

Applied Materials has focused expertise and investment in its Xi'an, China, 200mm development facilities to support customers' success in these technically complex and price-sensitive segments. There, hardware- and process development work is underway to enable new applications specialized for MEMS, power devices, thin-film batteries, and camera image sensors. In a previous issue, we focused on key advances for power device fabrication;^[12] here we highlight progress in MEMS-related processes.

Monolithic Integration

As die sizes continue to shrink, manufacturers strive to more efficiently package MEMS and CMOS devices. While several hybrid system-in-package devices have been developed, the industry trend is toward monolithic integration of CMOS and MEMS devices. This approach raises a number of new issues.

LOW-TEMPERATURE SILICON GERMANIUM (SiGe):

Polysilicon up to 60µm thick is currently used to fabricate most of the MEMS mechanical structures. However, its deposition rate at the low

process temperatures (<400 °C) necessary to avoid damaging the CMOS during MEMS integration is too slow to be production-worthy. SiGe offers a viable alternative to polysilicon as its mechanical and electrical attributes are equivalent or superior. In addition, its deposition rate is far higher at the lower temperatures required for full monolithic integration with CMOS. Nevertheless, depositing it in the thick layers required for MEMS is a challenging balance of stress and in-film particle control.

Applied Materials has successfully developed the only commercially available production-worthy, single-step/single-pass process for depositing thick SiGe. Using plasma-enhanced CVD (PECVD) on Centura DxZ or Producer mainframes, the process deposits a series of 2µm layers for a total thickness of 10µm. It is undergoing further refinement to enable deposition of layers more than 5µm thick with even fewer particles per pass. At the targeted total thickness of 40µm, it will meet customer roadmaps for comparability with today's polysilicon layers (see figure 3).

PARAMETERS	TARGET REQUIREMENT	ACTUAL
WTW Uniformity	+/- 5%	< 3%
WIW Uniformity	+/- 3%	< 2% 1 sigma
Ge Content	60-65%	≥ 60%
Thickness	0-10µm	≤ 15µm
Maximum Temperature	425°C	≤ 420°C
Deposition Rate	> 100 nm/min	236 nm/min
Resistivity	< 5mΩ-cm	< 4mΩ-cm
Residual Stress	100 - 150 MPa (Comp)	130 MPa (Comp)

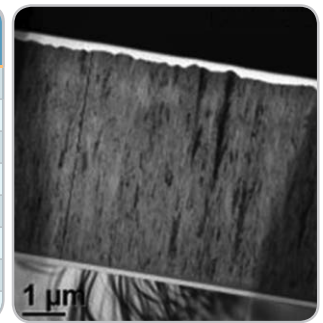


Figure 3. Applied's state-of-the-art, low-temperature SiGe deposition process is targeting >5µm/pass; the 4µm-thick layer in the SEM image shows the desired crystalline characteristics.

PARAMETERS	SI-RICH NITRIDE	CONFORMAL NITRIDE	SiN	SiON
WTW Non-uniformity	< 2%	< 2.0%	< 2.0%	< 2.0%
WIW Non-uniformity	< 2%	< 1.5%	< 1.5%	< 1.5%
Refractive Index	> 2.5	1.96 - 2.00	1.86 - 2.00	1.70 +/- 0.02
Temperature	400 - 480°C	480°C	200 - 400°C	200 - 400°C
Deposition Rate	> 3k Å/min	600 - 700 Å/min	> 3800 Å/min	3600 - 7k Å/min
WERR	< 0.05	0.08	< 0.2:1	< 1.0
Residual Stress	Tunable	-100 +/- 50 MPa (Tunable)	-90 +/- 20 MPa (Tunable)	-100 +/- 50 MPa (Tunable)

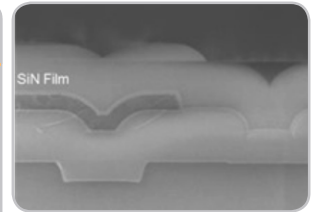


Figure 4. Applied's low-temperature SiN film forms a highly conformal, void-free layer with no delamination.

LOW-TEMPERATURE

CONFORMAL NITRIDE:

Monolithic integration poses even more complexities in the case of MEMS-based microphones. In these hybrid devices, two chips are packaged as a unit; one contains the MEMS and the second contains the CMOS. The MEMS structure creates significant topography and is also subjected to a somewhat lengthy release process step in hydrofluoric acid (HF). The silicon nitride (SiN) used as a barrier layer over the two components must be deposited at low temperatures (<400 °C) for CMOS compatibility. Further, it must be deposited slowly to ensure that the film forms a conformal layer and that its

crystalline structure results in a high wet etch rate ratio (WERR) with the sacrificial silicon dioxide removed by the HF. Monolithic integration with its CMOS drivers not only demands a higher deposition rate for production-worthiness, it means that the SiN layer may also be used as an electrically insulating dielectric, which imposes additional essential requirements for breakdown voltage and current leakage. Using the Producer PECVD platform, Applied has developed a low-temperature process that achieves not only a higher deposition rate without sacrificing WERR, but also conforms to the requisite electrical properties (see figure 4).

Ultra-Thick SiO₂ Deposition

Pressure sensor applications require thick films (> 20µm) that are suited to high-volume manufacturing (high deposition rates, better stress control, low particle counts). Deposition processes for both doped and undoped thick oxide have been developed on the Applied Producer PECVD system. These neutral-stress films can be deposited at increments of 5µm per pass with excellent particle performance (see figure 5). Continuing development work focuses on depositing greater thicknesses per pass while maintaining proportionally low particle counts.

All-In-One Etch

MEMS manufacturers were previously unable to perform the oxide hard mask open etch and deep silicon main etch steps in the same chamber. This situation increased wafer handling, added queue time complexities, and reduced overall throughput.

Based on the Applied DPS DTM 200mm deep reactive ion etch chamber, we have developed a two-step etch process (hard mask open, deep silicon etch) followed by a photoresist strip all in one chamber. Figure 6 shows representative results. Besides lowering wafer handling time and the overall cost per wafer, it improves the productivity of each chamber on the tool.

PARAMETERS	TEOS
WTW Non-uniformity	< 2%
Thickness	4.5µm
Maximum Temperature	≤ 350°C
Deposition Rate	> 1300 nm/min
Residual Stress	< 50 MPa (Tunable)
Refractive Index	1.4549
Defects	< 30 (> 0.2µm)

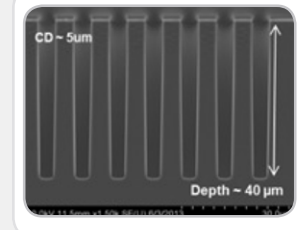
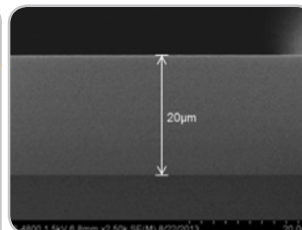


Figure 5. Applied's PECVD technology meets requirements for ultra-thick SiO₂ deposition with negligible particle counts.

Figure 6. Applied's all-in-one etch and resist removal process boosts fab productivity.

GROWING SCOPE OF 200MM APPLICATIONS DRIVES ADVANCES IN MEMS PROCESS TECHNOLOGIES

MEMS/CMOS Packaging

Bonding of MEMS wafers to CMOS wafers has become an increasingly popular method of integrating these devices in instances where the dual-layer bond interface uses aluminum and germanium (Ge) to form a hermetic seal between the two wafers and to simultaneously create selective electrical connections to bond pads between the two wafers. Volume production using this method depends on reliable delivery of a Ge layer at a high deposition rate and low particle count.

In this case, meticulous process tuning now enables Applied Endura PVD technology to deliver a pulsed DC process that deposits Ge at a rate exceeding 2600Å/min. with fewer than 200 particles at 200nm diameter (see figure 7).

FUTURE DEVELOPMENTS

The growing variety of MEMS devices and functionalities is leading to the adoption of new metals, dielectrics, and ceramic materials in the manufacturing flow. Many require specialized RF PVD processes to meet deposition rate, target erosion uniformity, or other specifications. Recent forecasts predict growth in a number of devices that use piezoelectric ceramic materials such as lead zirconate titanate and various lead-free alternatives for piezo-actuators or sensors, aluminum oxide for optical coatings or high-k applications, and vanadium oxide for next-generation microbolometer applications, among others.

As these emerging applications take hold, reliable manufacturing solutions will be needed that extend beyond

traditional pulsed DC PVD to enable manufacturability of these films and solve key issues such as deposition rate, uniformity, kit life, target erosion, pasting efficiency, and so forth. To address these anticipated customer needs, Applied is developing a new 200mm RF PVD chamber capable of both RF and pulsed DC deposition. Besides MEMS, the chamber will serve applications related to power devices and LEDs.

SUMMARY

A small but steady resurgence in 200mm production has marked recent years, driven in large part by the consumer electronics and automotive segments for devices fabricated with non-leading edge die and profitably produced by these systems. MEMS account for a significant portion of this production and have posed challenges that Applied is solving by enhancing deposition and etch processes, and designing innovative hardware. Through our 200mm development facilities in Xi'an and collaborations with our

customers, we are pursuing continuous tool and technology improvement to support today's broadly expanding cost-sensitive More-than-Moore device classes.

Thanks to Jeannette Hoffman for her contributions to this article.

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PARAMETERS	ACTUAL
WTW Non-uniformity	< 2.6%
Thickness	≥ 540 nm
Maximum Temperature	< 400°C
Deposition Rate	> 260 nm/min
Residual Stress	~ 220 MPa
Bulk Resistivity	~ 48 ohm.cm
Surface Roughness	~ 3.78 nm
Particles	< 200 (> 0.2µm)

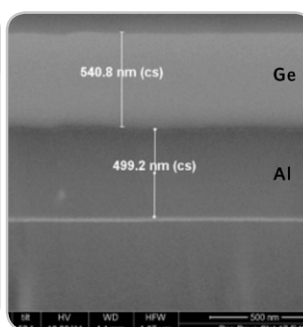


Figure 7. Enhanced Endura PVD technology delivers thick Ge film needed for MEMS/CMOS packaging.



ADVANCED SERVICE COLLABORATION— THE FAB'S NEW NORMAL

**BY
NANOCHIP
STAFF**

Faced with daunting semiconductor manufacturing challenges, chipmakers increasingly collaborate with Applied Materials service experts to pinpoint and resolve high-value problems in their fabs.

ADVANCED SERVICE COLLABORATION— THE FAB'S NEW NORMAL



Given the explosive growth in smartphones and mobility products, today chipmakers have relentless cost- and cycle-time pressures, whether they're building state-of-the-art microprocessors, NAND devices, or MEMS and power chips. Their manufacturing mandate is for equipment services that are more insightful, capable, and designed to forestall problems that can impact tool productivity and line yield. For example, as semiconductor companies moved beyond 28nm design rules, many of them hit various technical walls, with edge die yield and chamber matching among the most challenging manufacturing-related problems.

When it comes to service, Frank Nading has seen a dramatic evolution over the last three decades. Whether it's matching etch chamber performance, figuring out what's causing scratching during the CMP steps, or some other critical issue, semiconductor industry services now go far beyond conventional equipment support practices.

"Chipmaking is so complex now, and the cost of production is staggering. More than ever, our customers ask for help to accelerate yield, reduce cost and improve productivity of their Applied tools and their fabs," Nading said. "So today, when Applied brings service to the fab, we bring technology."

FROM DISCOVERY TO EXECUTION

Nading, who has spent nearly his entire career at Applied Materials, said his job as a solutions architect within Applied Global Services (AGS) is to work with customers to discover their particular challenges, then help shape service solutions that address their technical and economic situations.

"All fabs have problems," he noted. "Most customers do some level of service on their own. But sometimes there are tough problems—the kind that are costing them time, quality and money—that they need help to resolve. That's what we try to do: help them solve problems faster and at an affordable cost."

The initial job of the solutions architect is the discovery process, or as Nading describes it, "engaging directly with the customer at a very high level to find out what the real problem is."

The next step is proposing a specific solution, a methodology for getting to the root cause of the problem. "We do an assessment and say to the customer 'this is what you need to do to fix the issue.'" The solutions architect then works with the customer to determine the right blend of in-house and Applied Materials expertise to deliver the required solutions.

Execution is the final step: proving that the Applied Materials service team has the right mix of expert engineers and tools to solve the problem. "A key aspect of successful execution is setting expectations correctly, being specific about what the AGS team will deliver, and then delivering on those commitments," Nading said.

BENCHMARKING NEEDED

AGS Vice President and General Manager Charlie Pappis says his organization exists solely to enable customer success. "Increasingly, our job is to help customers fine-tune processes for optimum performance and manage on-board technology so they can predict and prevent problems before they impact device performance and yield."

Often, this starts with an important first step: benchmarking.

"Part of the fab service value we bring is benchmarking," Pappis said. "We look at what is best-in-class performance around the world—using aggregate data from hundreds or thousands of installed tools in a given class—then compare it with the customer's tools. Most of the time there's a significant gap."

Nading said a customer may report that uptime on a certain toolset is 70%, while Applied's own data may peg best-in-class at 85%. "That often initiates a good discussion about how the AGS team can work with the customer to improve uptime, throughput or yield," he said.

AGS's FabVantage Consulting Group is a team of highly specialized experts who work with customers to identify and resolve specific yield-, throughput- and other



Frank Nading, Applied Global Services (AGS) solutions architect

IMPROVED WITHIN-WAFER THICKNESS UNIFORMITY BY 50%

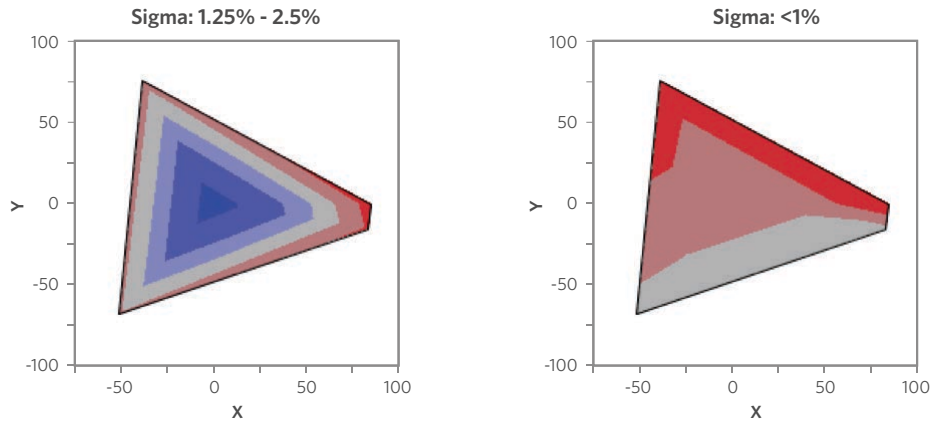


Figure 1. Reduced process variability is one outcome of Applied FabVantage offerings. At one fab, the FabVantage team was able to significantly improve process control on an Applied Centura Epi system by finding and correcting hardware issues and by optimizing the PM procedure.

productivity problems. Helen Armer, senior director of services technology, manages the knowledge base within the FabVantage Group. Armer said many customers ask Applied Materials for benchmarking to see how their tool or fab performance aligns with standard performance against a large set of similar tools. “This benchmarking often initiates a larger FabVantage engagement with very precise goals and objectives. Customers can then use Applied services to achieve and maintain these improved performance levels via a more comprehensive services agreement,” she said.

Pappis noted that besides tool control, cost competitiveness is driving an increased customer emphasis on factory utilization. “Factory utilization rates are rather strong right now. As these rates climb, new modules can become bottlenecks. However, often a percent increase in throughput for a certain toolset can result in a percent increase in the throughput for the overall fab. FabVantage assessments can uncover opportunities for improvements in these areas as well,” he said.

Jeremy Read, AGS vice president of Services Marketing, noted that FabVantage consulting is a key component of Applied Performance Service and Managed Service contracts, which are based on preconfigured tool- or on-wafer results. “Over the last few years, an increasing number of customers at all technology nodes have engaged with us for this capability, recognizing that it helps them achieve their difficult device-performance, yield and cost-reduction goals.”

THE EVOLUTION OF SERVICES

Services in the chip industry have evolved in stages. First, the shift from the original break-fix model—where corrective maintenance, spares delivery and cost were paramount—to something more complex started when foundries and memory companies began focusing more on cost of ownership.

Armer said that today high-k/metal gates, FinFETs, double patterning, vertical NAND, and other technology challenges have driven chipmakers to partner more closely with Applied, using the company’s TechEdge Technology Services, a new class of advanced service offerings.

“These services rely on sophisticated data analysis techniques coupled with the capabilities of specially trained service engineers,” she said. “When integrated with benchmarking assessments, they can help customers better understand what’s going on with their tools and processes, and often uncover multiple opportunities for productivity improvements.”

Read said that keeping tools within a tight on-wafer specification, and matching chambers across multiple tools, are high priorities at device makers. “One thing that goes across the board is the need to reduce process variability, although the amount of reduction depends on the process.

“Both of our outcome-based service offerings are intended to reduce process variability. With Applied Performance Service, the contract spec is based on wafer data gathered using UVA [univariate analysis] and MVA [multivariate analysis] along with metrology feedback. For Applied Managed Service, the contract spec is built on tool data using UVA and MVA and test structures,” he added. “The results can be quite dramatic. For example, for one customer thickness non-uniformity on Applied Centura epi systems was cut by more than 50%.” (See figure 1).

Read noted that the complexity of today’s device manufacturing environments requires a wider range of service capabilities than ever before. “We’ve now evolved beyond what has been considered normal service deliverables—routine tool maintenance activity and tool performance services—adding those focused on helping customers achieve desired on-wafer results and specific device-performance characteristics. Through service agreements incorporating advanced analytical tools,

ADVANCED SERVICE COLLABORATION— THE FAB'S NEW NORMAL



we are able to offer measurable operational excellence in yield, output, cycle time, and other key metrics that help customers attain their business and technology goals,” he said. (See figure 2.)

DATA SHARING NEEDED

The proliferation of sensors, data analysis tools and modeling methods in the fab opens the door to new service offerings that go far beyond traditional maintenance practices. But they can't perform without sharing of data and IP.

Pappis said “it's hard to envision customers universally allowing access to their yield and parametric data, only because their business is based on the unique IP associated with the data. So we propose going in with UVA and MVA capabilities that are generic to a target module.”

“There are more than 1,000 unique tool-types in Applied's installed base. Although they are different, they share many design, process and performance similarities. By overlaying data, we can quickly identify potential problem areas,” Armer said, noting that FabVantage has completed more than 180 projects and accumulated data collection plans for more than 650 tools since its inception in 2009.

AGS as a whole has about 3,000 customer engineers (CEs). Each year, a number of CEs are selected to undergo the training required to be TechEdge engineers, using software tools and models that run within the Applied E3 fab management platform. These TechEdge applications analyze data from a collection of priority sensors and

“Both of our outcome-based service offerings are intended to reduce process variability. With Applied Performance Service, the contract spec is based on wafer data gathered using UVA [univariate analysis] and MVA [multivariate analysis] along with metrology feedback. For Applied Managed Service, the contract spec is built on tool data using UVA and MVA and test structures. The results can be quite dramatic. For example, for one customer thickness non-uniformity on Applied Centura epi systems was cut by more than 50%.”

– Jeremy Read

supporting capabilities such as rapid diagnostics, variability reduction, chamber matching, and a growing number of other capabilities.

Nading said that Applied is actively building a knowledge base that plays an increasingly important role in the development and delivery of advanced services. “Today we have the ability to look at individual components on a tool. Where we want to go with TechEdge services is to take the sensors we know are important to on-wafer results and create multivariate formulas that accurately predict on-wafer results. We are investing a lot of time, effort and money to develop and deliver those capabilities.”

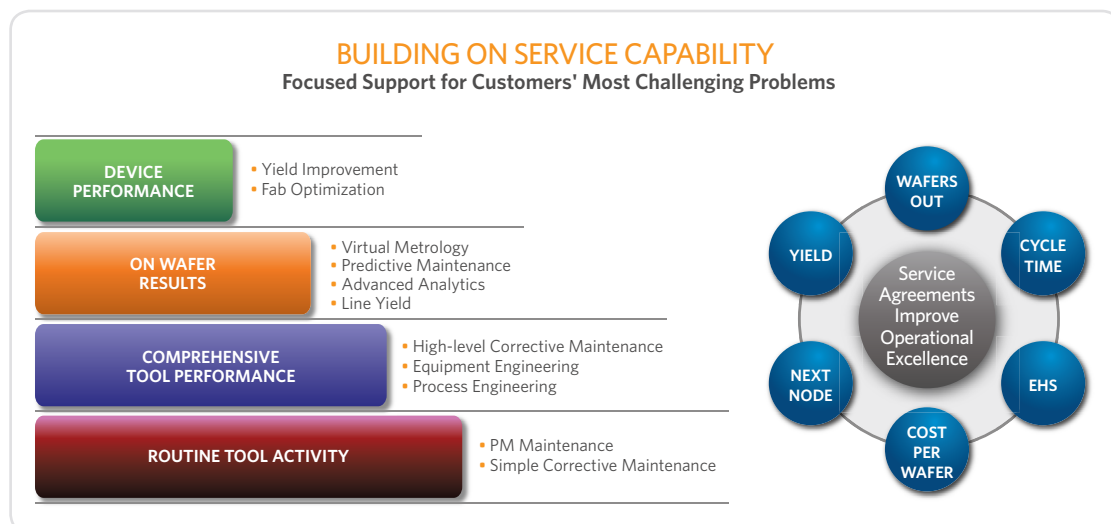


Figure 2. Applied Performance Service and Applied Managed Service agreements focus on achieving customer-defined device-performance and on-wafer results using a variety of FabVantage consulting and TechEdge services.

PMs STILL IMPORTANT

Tim Trudgeon, a director in the FabVantage group, said he has witnessed a dramatic change in the willingness of customers to engage with Applied Materials service teams. “I see a tremendous amount of collaboration, especially in FabVantage projects, to match chambers or reduce defects. Once customers understand that our people have the right expertise, they pull us in and make us part of their team.”

Trudgeon, who joined Applied in 1999, said many of the TechEdge advanced services delivered by AGS require “a mix of people with a high-level statistical data analysis background as well as those with a solid understanding of the hardware and the semiconductor fab. We want to be sure that the direction of the statistical analysis is correct. But it’s only when you combine that ability with people who understand how the tools work, how the process works, and the flow of manufacturing, that you get significant results.”

And yes, that trained CE plays a key role. Matching the performance of a fab’s etch tools across multiple chambers involves many factors. A FabVantage team may identify the variables to keep chambers matched, with well-qualified maintenance people playing a key role. “It is really important to do a PM [preventive maintenance] properly, and PM routines at 20nm are much different than at 65nm. We have got to connect all the dots from a maintenance perspective to sustain that tool and chamber matching for a long time,” Trudgeon said.

“We are trying to move our whole service business upstream. Instead of a model about how we meet a certain uptime metric, which is a tactical goal, we increasingly are helping customers meet strategic targets for end results such as on-wafer performance,” he added.

Trudgeon said a FabVantage team just concluded a chamber-matching engagement that has led to a longer-term service agreement with the customer. The FabVantage team identified key variables contributing to etch CD variation, and suggested a series of fixes to the tool setup. “We provided the analytical ability to monitor the sensors on the components that matter. Everyone has FDC [fault detection and classification], but not everyone has the deep understanding of the equipment needed to know which sensors and components matter, and what are the appropriate statistics to apply to those sensors.”

Once the FabVantage team determined which components tended to drift, the next step was working with the customer to develop a maintenance program “so that the chamber matching is sustained over time. This kind of analysis and advanced service has proven to be a big draw from our advanced-node customers,” Trudgeon said.

DR. WATSON, I PRESUME

In that sense, the semiconductor service business isn’t much different from many industries, where human professionals are supported by computers and knowledge databases. Physicians, for example, draw upon knowledge databases to augment their own diagnostic skills. And who can forget the pounding that two human contestants took on the JEOPARDY! game show at the hands of IBM’s mammoth Watson supercomputer?^[1]

Applied Materials is building its own Watson-like abilities to find answers for customers—ideally before problems become manifest.

TechEdge services can be deployed to meet the key performance indicators in a particular service contract, Trudgeon said. Depending on the goals within a service contract, TechEdge engineers might prioritize certain sensors on a tool and develop the appropriate statistical analysis, pulling sensor trace data into Applied E3 at regular intervals or in real time, as needed. Priority sensors would be compared to proven models to better understand when there might be a component failure, the goal being to reduce scheduled downtime and better plan maintenance events.

“If the KPI is etch chamber matching, we would use TechEdge services to monitor and control when the tool needs to be maintained, for example,” Trudgeon said.

“With TechEdge and FabVantage capabilities, we are building a very broad understanding about what goes on in fabs. We know a lot about how the elephants are running, and that makes us much better equipped to help solve customer challenges faster,” Nading said.

Asked to conclude where Applied’s service business is today, he replied: “I think it’s evolving. And that service that may not have been a fit for you last year, well, now you should look again because it’s constantly changing. I like to think we’re getting better all the time.”

Pappis summed it up this way: “To think that fabs can do it on their own is probably not true, and to think the OEMs can do it on their own is probably not true. It has to happen together.”

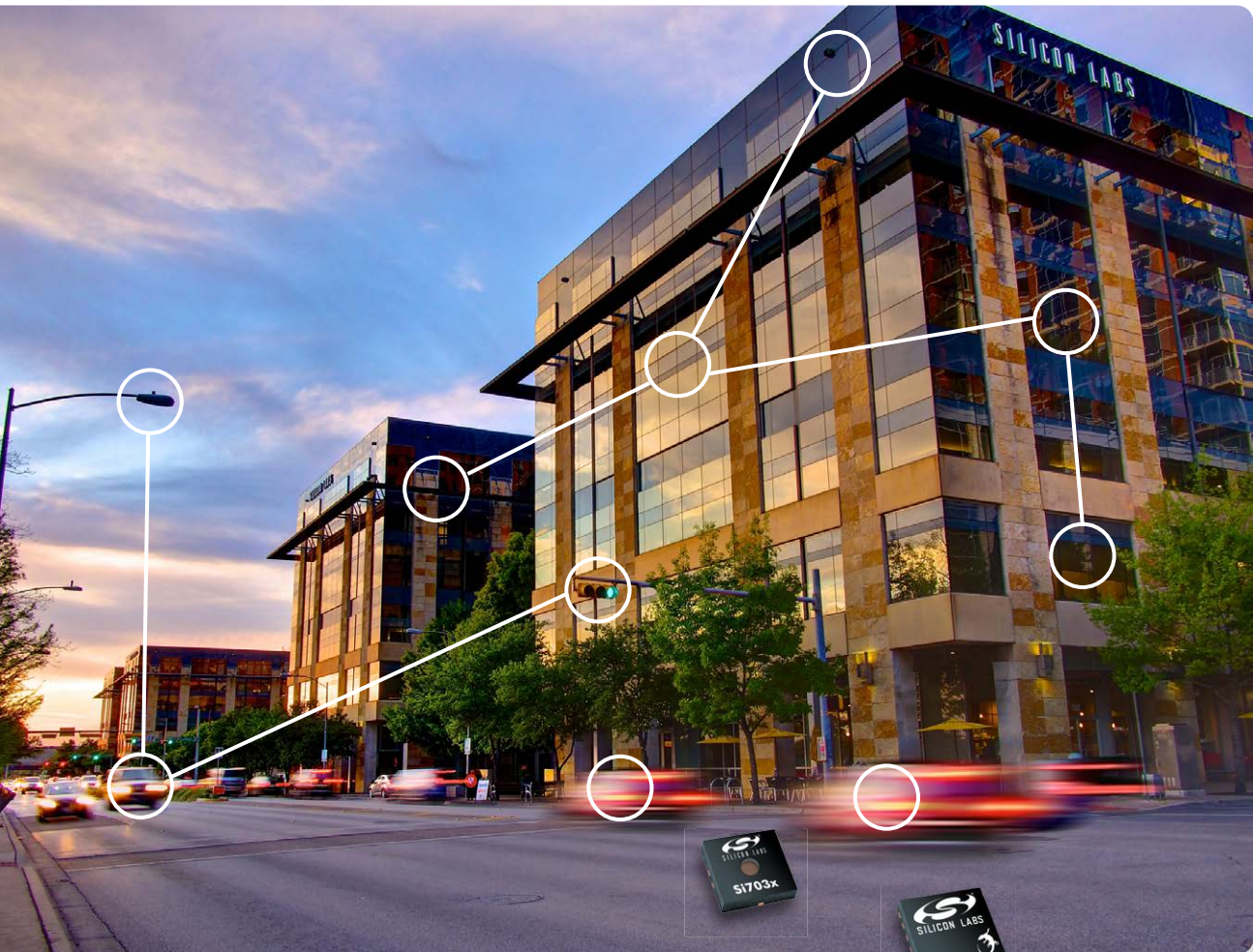
For additional information, contact nanochip_editor@amat.com

^[1] JEOPARDY! is produced by Sony Pictures Television, and is broadcast in 29 countries outside the U.S. http://www.nytimes.com/2011/02/17/science/17jeopardy-watson.html?pagewanted=all&_r=0

“To think that fabs can do this on their own is probably not true, and to think the OEMs can do it on their own is probably not true. It has to happen together.”

– Charlie Pappis

SILICON LABS TACKLES IoT CHALLENGES



Providing silicon to the IoT market requires a maniacal focus on power consumption at 180nm and 90nm design rules. Silicon Labs is succeeding in combining low-power wireless, MCUs, and flash in its SoC products.

BY DAVID LAMMERS



Tyson Tuttle, CEO
of Silicon Labs

The semiconductor industry is looking to the Internet of Things (IoT) to drive new demand as traditional sectors such as PCs flatten out or decline. To understand what it takes to create successful IoT solutions, a close look at Silicon Labs in Austin, Texas, illustrates how the mix of cost, low-power wireless, and other factors makes the IoT market as different as a sushi bar is from a barbecue joint.

Founded in 1996 by three veteran mixed-signal designers, Silicon Labs started out with the goal of applying standard foundry CMOS to non-traditional applications, including RF. That RF CMOS foundation, according to the company's executives, prepared Silicon Labs for the IoT market, where wireless data transmission is a key part of the IoT equation.

After industrywide slow-growth years of the financial downturn, the company's board of directors

promoted Tyson Tuttle, who had started at Silicon Labs as a wireless design engineer, to the CEO position in March 2012, charging him with finding faster-growing markets. Tuttle focused the fabless 1,100-person company on IoT solutions, where the company's portfolio of microcontrollers (MCUs), RF and sensor solutions would form a foundation. About a third of the company's revenues now come from IoT markets; in the first calendar quarter of 2015, revenue from that sector was about \$61 million, up 26% year-on-year.

"To be able to integrate the wireless function together with the microcontroller, you have to be in the same process technology," Tuttle said in a recent industry presentation. "Then you must have the flash memory integration, and you have to figure out how to make all of the wireless connectivity work in the

presence of all that digital processing going on." In the IoT marketplace, he added, power consumption is as important as cost, because many of the end-node products are expected to run on coin cell batteries for years at a time.

AN IoT ACQUISITION STRATEGY

During his tenure as CEO, Tuttle has led three key IoT-related acquisitions: Ember (Boston), an early pioneer of ZigBee wireless solutions; Energy Micro (Oslo, Norway), which developed a series of low-power ARM-based 32-bit microcontrollers; and most recently Bluegiga Technologies (Espoo, Finland), a provider of Bluetooth and Wi-Fi wireless solutions for wearables and other applications.

Because IoT solutions are used in thousands of different applications, with tens of thousands of customers, Tuttle noted that "you have to build these SoCs in ways that are very general purpose." Some of the biggest markets, he said, are smart metering for energy, water, gas, and heat; a range of wearables; home automation and security; diverse industrial and factory automation applications, and RFID and digital shelf labels for retail customers.

POWER CONSUMPTION IS KEY

Sandeep Kumar, senior vice president of worldwide operations at Silicon Labs, said, "The key challenge is that these end-user node devices for the IoT are wireless.

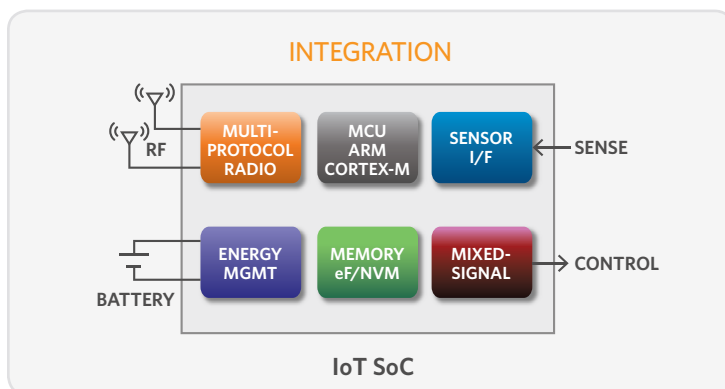
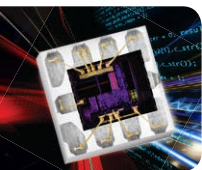


Figure 1. An IoT SoC is a highly integrated device that combines an MCU core, mixed-signal peripherals, a multi-protocol wireless transceiver, energy management circuitry, and non-volatile memory into a single die manufactured on mainstream CMOS process technologies.



SILICON LABS TACKLES IoT CHALLENGES

Whether they are smart energy meters or health monitors or security systems, they will all deliver their data into the network and cloud through low-power wireless. And, a motion sensor or a door sensor has to last 5 to 10 years on a cell battery."

Kumar started his career at Bell Laboratories in New Jersey. He left Agere Systems to join Silicon Labs in 2006 to oversee the company's manufacturing strategy. A key part of this strategy was an initiative to drive design-for-cost for Silicon Labs' IC products. This methodology involves a variety of manufacturing inputs and variables, ranging from process technology to test coverage, to determine the most cost-effective manufacturing solutions.

"We did a very detailed analysis of what would happen if we moved [from 180nm] to 110, 90, and 55 nanometers, through our design-for-cost process. The chip design team is a critical part of this process. To achieve our performance and cost goals, we concluded that the sweet spots for our IoT portfolio were 180nm and 90nm. We also continue to look at smaller geometries. We need embedded memory for many of our IoT devices, and yet nothing is available at 28nm or 40nm. We have concluded that with the features and performance we need in our SoCs, 55nm was not the most cost-effective process node for our IoT manufacturing needs," Kumar said.

Many of Silicon Labs' components are made on 200mm wafers at 180nm design rules, and that 180nm-based portfolio is growing. Other IoT-centric SoC devices, where larger blocks of flash and RAM memory are needed or faster processing is required in a smaller die size, are being targeted to 90nm foundry processes on 300mm wafers. (Other Silicon Labs products,



Sandeep Kumar, senior vice president of worldwide operations at Silicon Labs

such as digital TV tuner ICs, are made on 55nm technologies.)

At a SEMI event held in Austin in mid-May, Kumar said a growing concern is fab availability. "All the 180nm fabs are full, which is kind of counterintuitive. That has never happened before, to my knowledge. All of the foundries are on allocation at 180nm because of the demand for sensors and other trailing-edge devices."

Daniel Cooley, vice president and general manager for MCU and wireless products at Silicon Labs, said the boom in smart-card chips is one application sopping up 180nm capacity. "There is a shortage of 180nm capacity worldwide. Every time there is excess capacity at TSMC we buy it, because we don't know when we will get excess again. We call them every week, asking 'Did anybody cancel? Did anybody push out?'"

RF FUNCTIONS COME LAST AT FOUNDRIES

Foundries traditionally start out by building a new process aimed at high-performance servers or smartphone processors; only later do foundries offer non-volatile memories and support for wireless.

"The last things are the RF parameters. RF is one of the hardest things to do, because these processes were designed from the ground up to handle digital," Cooley said. The foundries have to add mask layers, or

additional metal layers to provide the capacitors and inductors needed to create RF and passive components. A foundry often will add transistors with a higher threshold voltage to reduce power consumption, especially when the device is in sleep mode.

"In terms of manufacturing, there are only a few fabs out there available to fabless companies that can do all of this," Cooley said.

FINDING BUSY FABRS KEEPS COST DOWN

Kumar said an important investigation for Silicon Labs is determining how much foundry capacity will be available in the future, and estimating the yields and wafer costs at those fabs. If a foundry partner has a nearly full 200mm fab and a half-full 300mm fab, "there is no question" that the 200mm fab will be cheaper, he said.

"One question we ask our suppliers is how they see their capacity in five years. It is a fine line; we don't want to be in a node that is oversubscribed either, so you don't get capacity. We want to be in fabs that are very busy. We don't want to be in a fab that is only 50 percent utilized, because then we are likely to see an increase in price, or a fab shutting down," Kumar said.

Applying what he calls "intuitive science," Kumar queries his suppliers to find fabs that are likely to be 90–95% utilized in three years. Last year, two fabs were shut down in Germany and Korea; Kumar said Silicon Labs had predicted those closures because utilization rates were so low that the fabs were losing money.

Kumar said he is keeping a close eye on the limited availability of used 200mm fab equipment. "We have very confidential meetings with our foundry partners, where we share our 5- and 8-year plans. We learn from them the factual data of how they plan to invest, and how they see customers moving from 200mm into 300mm that will open up 200mm capacity."

Kumar also said TSMC “is giving us capacity” because they see Silicon Labs as a key player in the IoT space, given its fabless nature. Other big players in IoT chips have their own fabs and won’t provide the major foundries with much IoT-related business.

And Silicon Labs needs partners to augment the capabilities of its engineering staff to keep up with the myriad projects the company has on its plate. “I wish we could go out and hire a hundred engineers to handle all of the projects we have on our wish list, but our financial guys have different ideas,” Kumar said, laughing.

The back end also presents unique challenges. IoT chips are so small and lightweight that they can literally float in the air during the testing phase. Silicon Labs has developed test algorithms to deal with the combinations of flash, control logic, and RF circuitry on its wireless microcontrollers. It uses built-in self-test (BIST) extensively. Noting the cost limitations facing nearly all IoT end-node markets, Kumar said semiconductor companies “must plan for a commoditized market. We are selling all of this functionality for the price of a slice of pizza.”

Adding flash adds about 30% to the number of mask layers. The major foundries are investigating new types of non-volatile memory, such as magnetic RAM (MRAM), ferroelectric RAM (FRAM), and resistive RAM (ReRAM) that could be embedded at less cost. In about

“All the 180nm fabs are full, which is kind of counterintuitive. That has never happened before, to my knowledge. All of the foundries are on allocation at 180nm because of the demand for sensors and other trailing-edge devices.”
– Sandeep Kumar

five years, embedded flash could be a thing of the past, Cooley predicted.

The amount of SRAM data memory on the company’s IoT devices is growing. “In MCUs, there used to be a rule of thumb, an 8-to-1 ratio of flash to SRAM, with in some cases a megabyte of flash and 128k of SRAM,” Cooley said. Now, that ratio is swinging to 3-to-1, or 2-to-1, with perhaps a megabyte of flash and 512k of SRAM. The change relates to the need to save on battery power, provide the memory necessary for wireless networking stacks, and even buffer the frames of small displays for wearable devices.

IoT applications often are in sleep mode nearly all of the time, waking up only to send data to the cloud. With a large chunk of SRAM, the SoC can store data autonomously from sensors and other peripherals. Once the buffer is full, it can send data to the cloud, or trigger the MCU to wake up. “With more SRAM, there are more things you can do when the MCU is off,” said Cooley.

And compared with flash, RAM-based buffers are faster to read, and require less power to write due to the large charging pumps on flash.

In short, RAM is lower power, and faster to access, than flash.

A NEW ERA OF MICROCONTROLLERS

Cooley said the need for IoT devices to wirelessly deliver data to the cloud differentiates the IoT from traditional embedded markets, where MCUs were often standalone devices.

“I think you are starting to see in the market a new class of wireless microcontrollers. They are not MCUs, and not wireless chips dedicated to a single function,” he said, arguing that few companies have the design expertise to combine a low-power MCU with RF capabilities in a foundry process.

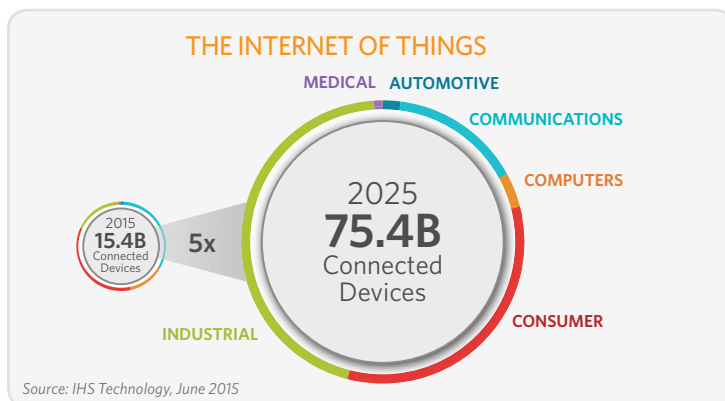
Cooley also said wireless MCUs present firmware challenges to companies that have specialized either in MCUs or wireless ICs.


“Only a few companies have the deep software knowledge to do wireless stacks in what we believe is a new class of devices. The software, the RF in CMOS, and the core MCU—you have to put all three together to succeed in the Internet of Things market.”

Tuttle noted that other companies will have their work cut out for them to catch up with Silicon Labs in the IoT space.

“We have been building our IoT capability for five years, and we feel we have a several-year lead over what other companies have. It is a subtle point, but it is not easy to integrate these functions in the same technology, and add flash memory, and make it all work. It is difficult if you haven’t done this before.”

For additional information about Silicon Labs visit www.silabs.com



The background of the entire page is a photograph of ocean waves. The water is a mix of light blue and white, with the white foam of the waves creating a textured, rhythmic pattern. The waves are moving from the top left towards the bottom right, creating a sense of motion and depth. The lighting is bright, suggesting a sunny day, and the overall tone is clean and natural.

TRENDS IN SUBFAB ENERGY CONSUMPTION AND EMISSIONS CONTROL

BY
ANDREAS NEUBER,
MAXIME CAYER,
SHAUN CRAWFORD AND
ANDREW HERBERT

BACKGROUND

The semiconductor industry has made great advances over the last few decades, but multiple challenges must be overcome for that progress to continue. Among them is the need for companies to move along a sustainable growth path. That need is driven by the increasingly short supply and growing expense of resources critical for semiconductor manufacturing, such as water and power.

What does this mean for the semiconductor manufacturing industry going forward? Energy-saving technologies and products may have a significant positive impact, and are widely recognized as useful ways to promote sustainable growth. Variable-frequency ICs to drive pump motors are one example. Another is the synchronization of fab and subfab operations to optimize subfab resource consumption with no risk to the manufacturing process or throughput.

Energy savings will assume an even greater importance in the years ahead. Many regions now require that power and resource consumption, and emissions, stay at an even level as production capacity increases. And this is occurring as cost-reduction pressures in all phases of semiconductor manufacturing are stronger than ever.

The good news is that energy conservation, reduction of greenhouse gas emissions (GHGs) and cost reductions do not necessarily contradict one another. For example, the high operating costs to effectively abate environmentally harmful perfluorocarbon (PFC) gases can be reduced by applying alternative technologies, such as pre-pump plasma abatement. Pre-pump abatement reduces power consumption and generation of typical byproducts such as nitrogen oxides (NOx).

However, such solutions must be available both for new tools and for existing fabs with reasonable rates of return on investment. The ability to achieve an attractive ROI within one to three years depends on many factors—the cost of energy and other resources being a major component. Also, measures implemented to save energy and resources must not negatively impact manufacturing or result in increased safety or fab operation risks.

SUBFAB UPDATE

Today, the focus on saving energy and resources has shifted from facility operations to the subfab, for several reasons:

- The subfab currently consumes more energy and resources than any other part of the production facility (see figure 1).
- Most fabs no longer have much low-hanging fruit—easy opportunities to drive improvements in resource efficiency—thanks to improvements already made over the past few years in facility operation.
- Because changes in the subfab apply only to auxiliary processes, it is possible to retrofit equipment or implement other changes in existing semiconductor subfabs without having to requalify manufacturing processes.

Figure 1 shows the power consumption of a fab by specific application, while figure 2 shows the major distribution of power in a fab. Note that figure 1 is incomplete to some extent, because, in addition, the consumption of other utilities is primarily driven by the variable needs of the manufacturing equipment.

If one also considers indirect power consumption, based on the SEMI S23 Guide for Conservation of Energy, Utilities and Materials, the portion attributable to manufacturing equipment would be even larger. More than 80% of a fab's power consumption is driven by the needs of the manufacturing process itself, and only 20% by the infrastructure.

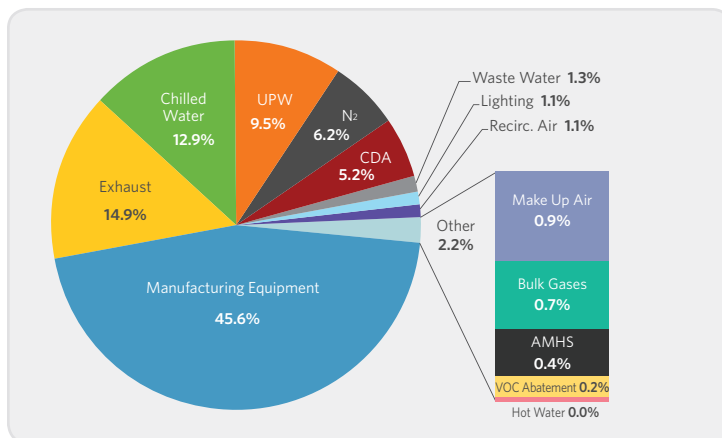


Figure 1. Breakdown of power consumption in a fab by specific application.

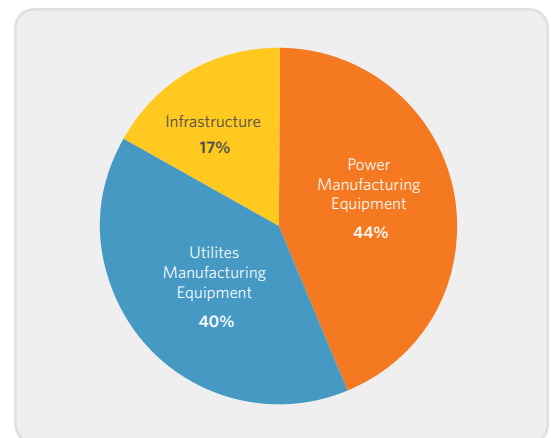


Figure 2: Distribution of power consumption in a fab.

TRENDS IN SUBFAB ENERGY CONSUMPTION AND EMISSIONS CONTROL

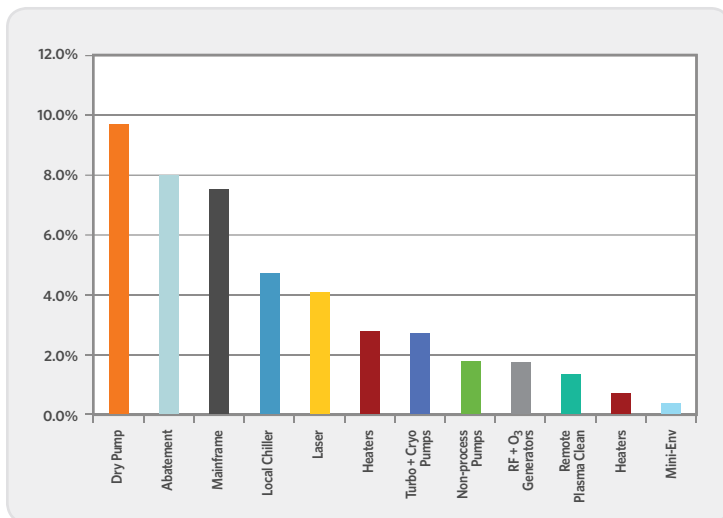


Figure 3: Pareto diagram showing the typical power consumption of key components of a fab's manufacturing equipment.

Figure 3 shows the power consumption of key components of a fab's manufacturing equipment. Dry pumps and abatements are some of the biggest energy and resource consumers. Along with pipe heaters, they are the major components that can be most improved without impacting production, because they are downstream of the process.

SYNCHRONIZATION CONSERVES RESOURCES

The Applied Materials iSYS controller is a device that communicates between a wafer processing tool and its support equipment in the subfab. The controller receives data concerning tool and chamber status and the chemistries being run. It then provides signals matched to a chamber's specific requirements to trigger energy and resource savings in the support equipment, even under high-utilization conditions.

For example, the iSYS controller can reduce the total equivalent power consumption for a dry pump by 3–6% when a tool is at 95–100% utilization. Although specific results vary, in practice the fab-subfab synchronization it enables can reduce overall abatement and dry pump operating costs by up to 10% during high tool utilization. These savings are realized because the iSYS controller ensures the pump and abatement units switch to lower energy usage when wafers are not in production.

More than 1,000 semiconductor manufacturing tools have been connected to iSYS controllers since Applied introduced the device in 2009. The controller also provides real-time reporting capabilities to document energy consumption and savings, and allows users to monitor fluorinated greenhouse gases (F-GHGs) emissions and meet green operation reporting requirements.

In addition, the iSYS controller can help reduce NO_x emissions and volatile organic compounds (VOCs) generated by abatement. Other subfab components can be controlled as well, including pipe heaters (indirect savings from reduced N₂ flows), O₃ generators, local chillers, hot N₂ purge units, etc.

While the controller enables savings in normal production mode, when O₃ generators are used or when temperatures are changed, the system needs wake-up time to adjust to safe operating conditions. These energy-saving states are called sleep modes.

In addition to having a small footprint, the iSYS controller can easily be retrofitted and implemented, with minimal downtime and no effect on process parameters. Thus, whether a tool is running a process, sitting idle or being cleaned, use of power, gas and water is kept to a minimum—reducing the fab's carbon footprint and lowering costs.

STATUS, CURRENT ISSUES & FUTURE TRENDS

The importance of fab-subfab synchronization is increasing because more energy is required for abatement of PFC gas and N₂O emissions than for typical process gases. This is supported by extensive SEMI standardization efforts for idle and sleep-mode energy conservation; see for example SEMI S23, SEMI E167.1 and .2 (work in progress).

Currently Applied Materials is working to develop further improvements in the synchronized operation of both pumps and abatement. For pumps, the main areas of focus include:

- Independent speed and purge N₂ control
- Enabling the use of multiple N₂ levels

For abatement, the main areas of focus are:

- Providing increased information about the O₂ flowing from the process in order to reduce the need for oxidants in the abatement or in consideration of the caloric value from process gases

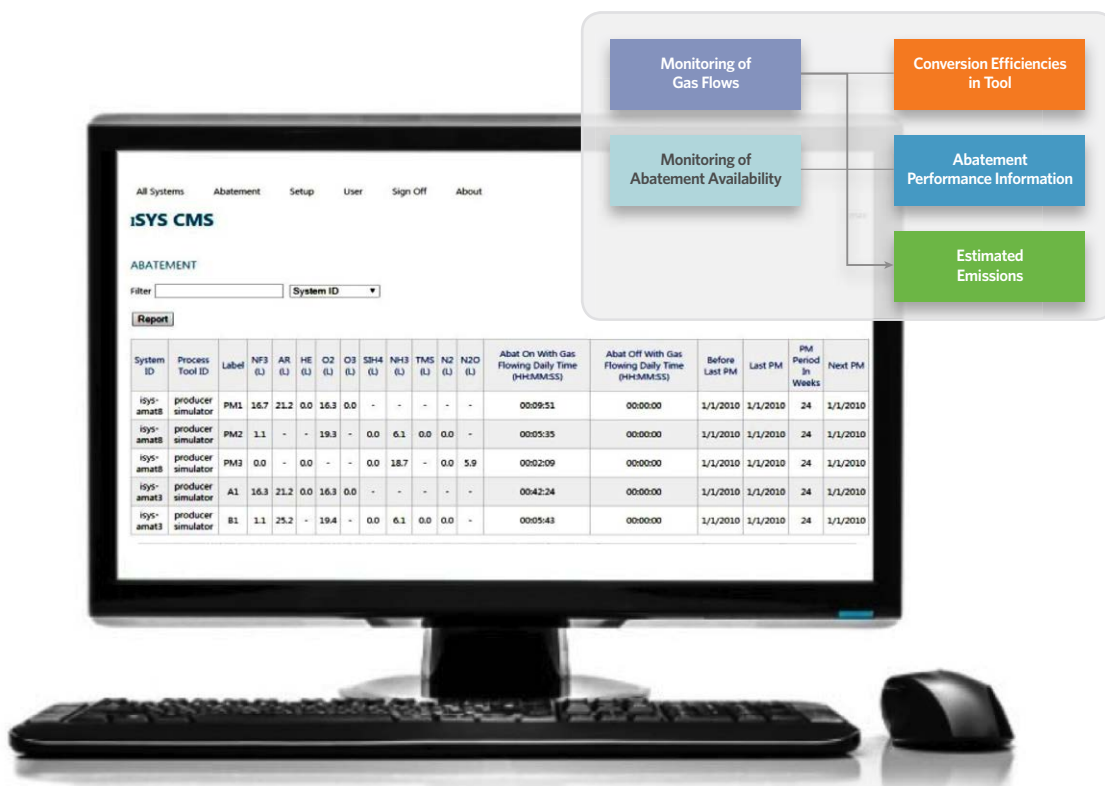


Figure 4. The Applied Materials iSYS controller gives users real-time data concerning energy consumption and savings, plus the ability to monitor performance and document fluorinated greenhouse gas emissions to meet reporting requirements for green operation.

- Independent control of the thermal reactor section and water scrubber
- Enabling multiple water-consumption levels depending on the gas-type
- Minimizing unnecessary purge flows

Another major trend in fab operation is the use of large and complex data sets. Subfab automation and data collection are currently lagging in this area, but the iSYS controller can collect information about gas flows as well as information from subfab components. This information can be used for:

- Resource consumption reporting, including equivalent energy consumption
- Reporting GHG emissions by correlating gas consumption, conversion and emission factors, as well as abatement availability
- Reporting of other environmental parameters
- Alarm reporting and management alerts for minor subfab components, e.g. pipe heaters
- Predictive pump maintenance

CONCLUSION

As energy and other resource costs increase, along with environmental sensitivities and government reporting requirements, it is important for semiconductor manufacturers to develop and implement sustainable manufacturing practices.

Fortunately, synchronizing the operation of a manufacturing tool and its support equipment is a safe, efficient and cost-effective way to save energy and reduce emissions with no negative impact on production.

Applied Materials' iSYS controller is a key technology that helps semiconductor manufacturers move along a path to sustainable growth by helping them lower costs, reduce environmental impacts and meet government reporting regulations for GHG emissions. It is also a proven abatement solution already in production at more than 30 fabs around the globe.

For additional information, contact andreas_neuber@amat.com

DEMAND FOR 200_{MM} TOOLS OUTSTRIPS SUPPLY

No doubt about it, 200mm wafer manufacturing is enjoying a strong rebound. Dan Tracy, senior director of industry research at SEMI, recalls an equipment refurbisher who last year “was bemoaning the state of his business.

A year later, he is very busy, and business is looking very good.”

BY DAVID LAMMERS

He’s far from an isolated case. Strong prices for 200mm equipment early in 2014 dropped off mid-year, then made a surprisingly strong rebound in the fourth quarter as foundries bought up 200mm equipment, according to Joanne Itow, managing director, manufacturing, at Semico Research. “Now, if you see a 200mm tool, you hang on to it.”

Supporting anecdotes abound. Emerald Greig, a veteran 200mm tools trader and now executive vice president of Americas and Europe at SurplusGLOBAL Inc., also sees tight 200mm tool availability. “There’s a lot less supply and a lot more

demand. It just kills me, because every day I could sell so much more if I had the equipment to sell. I get two to three requests that I cannot fill every day—minimum.”

Meanwhile, Daryl Karczewski, division director at Macquarie Equipment Trading, said the business is currently selling a used metrology tool for the same price as a new one, while during the downturn the same piece of equipment was valued at only one-tenth of that price. Additionally, eight of his 200mm lithography tools, which just 12 months ago were considered scrap and not worth refurbishing, are now

on the market for over one million dollars each.

Karczewski said he has seen positive movements in the market and a recent upturn in demand, commenting, “you know things are going well when you have customers in places like Russia, Brazil, and China looking for equipment. Refurbishers are sold out.”

For the Macquarie Group, an Australia-based investment bank with extensive experience in trading used semiconductor equipment, the current upturn means its customers are increasingly turning to arbitrage. “Arbitrage means chip companies tell



DEVICES BUILT ON 200MM IN 2015

Largely considered emerging technologies, these 200mm device segments include MEMS, power devices, CMOS image sensor (CIS), wafer-level packing (WLP) / through-silicon via (TSV)

SMARTPHONE AND TABLET PCs



Device Technologies	CDs
MEMS	0.7 μ m–2 μ m
PMIC	130nm–65nm
RF	90nm–1 μ m
Microcontroller	180nm–90nm
WLP & TSV	> 1 μ m

INDUSTRIAL APPLICATIONS



Device Technologies	CDs
MEMS	0.7 μ m–2 μ m
PMIC	130nm–65nm
Power Diode	> 1 μ m
Microcontroller	180nm–90nm

AUTOMOTIVE (Safety, Navigation, ECM, etc.)



Device Technologies	CDs
MEMS	0.7 μ m–2 μ m
PMIC	130nm–65nm
CIS	\leq 1 μ m
RF	90nm–1 μ m
Microcontroller	180nm–90nm
WLP & TSV	> 1 μ m

WEARABLES AND HEALTH MONITORING



Device Technologies	CDs
MEMS	0.7 μ m–2 μ m
PMIC	130nm–65nm
CIS	\leq 1 μ m
Microcontroller	180nm–90nm
WLP & TSV	> 1 μ m

Figure 1. A wide variety of systems, ranging from smartphones and autos to wearables, rely on trailing-edge devices made on 200mm wafers. (Source: Applied Materials)



DEMAND FOR 200mm TOOLS OUTSTRIPS SUPPLY

us, 'Here is the tool I need, and this is what I am willing to pay.' We then go out into the market to source a seller and negotiate a price," Karczewski said.

THE OEM VIEWPOINT

John C. Cummings, managing director of marketing and business development for the equipment product group at Applied Global Services (AGS), said the company's 200mm tool sales doubled from 2013 to 2014, and are expected to more than double this year. Cummings estimates that 80,000 new 200mm wafer starts per month (wspm) came on line last year, and that another 90,000 wspm will be added this year.

"Unfortunately, core prices are higher for everyone. With 90,000 additional starts per month, what will people do? Some can make the transition to 300mm, but others cannot," Cummings said.

That's a major issue because as fewer 200mm fabs close down and release equipment, OEMs like Applied Materials are finding fewer good-quality used cores to buy. "The cores we're buying now are not in such good condition or aren't as good a match as before. So, as the supply of used cores dries up, we are adding more new content to a used core. To do that, we are revitalizing our supply chain so we can meet demand by building some models of new 200mm equipment," Cummings said.

These days "used" equipment includes hybrids that range from a used core with new parts (and often, new chambers) to virtually new tools that start with a brand-new 200mm core and include mostly new parts and components. For example,

for 200mm epitaxial equipment, Applied's 200mm team starts out with a new Applied Centura mainframe and then adds as much used content as possible.

HOW LONG WILL IT LAST?

Why is the rebound so strong, and how long will it last?

Greig from SurplusGLOBAL said, "One reason is that a lot of the new technologies coming to the market surrounding the Internet of Things aren't made with state-of-the-art technology. Consumer stuff, like wearables, can get enough die per wafer by ramping up 200mm."

MEMS sensors such as accelerometers, gyroscopes and others are an example. They saw record volumes in 2014, according to Rob Lineback, an analyst at IC Insights, Inc., who authored the firm's Optoelectronics, Sensors, and Discretes (O-S-D) report issued in March. About two-thirds of the

11.1 billion sensors made last year were MEMS-based, and IC Insights sees an 11% compound annual growth rate to 19.1 billion sensors by 2019. [See related article "Growing Scope of 200mm Applications Drives Advances in MEMS Process Technologies" on page 2 of this issue.]

"There is also a lot of demand for analog and mixed-signal products, and nearly all of that is on 200mm," Lineback said. "Demand from mobile devices will stay strong, and most of the chips used in IoT end-use products will be made on 200mm wafers."

Does all of that add up to capacity constraints? "I haven't heard of anybody not being able to meet their orders yet, but everything points to that," Lineback said. "It's pretty clear it is a tight market right now to get the tools to add capacity, which is creating a little bit of a chess match. Especially if you think your competitor is going to get it, you might buy a tool even though you don't need it right away."

INSTALLED CAPACITY LEADERS PER WAFER SIZE AS OF DECEMBER 2014

(Ranked by Shares of Total Worldwide Installed Monthly Capacity)

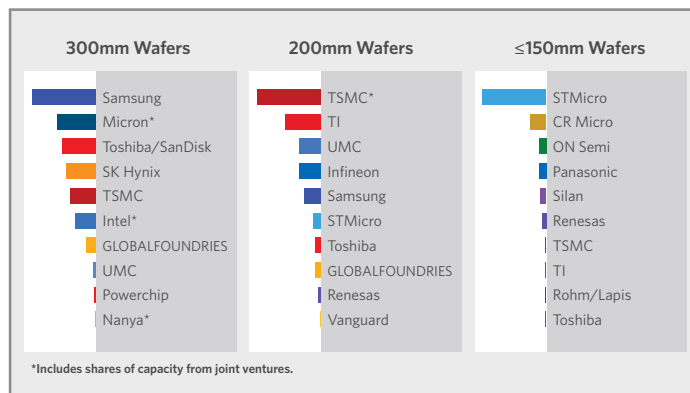


Figure 2. TSMC and its joint ventures own the most 200mm wafer fab capacity, while STMicroelectronics, a power in the MEMS sensor field, is the leading 150mm wafer processor. (Source: IC Insights)

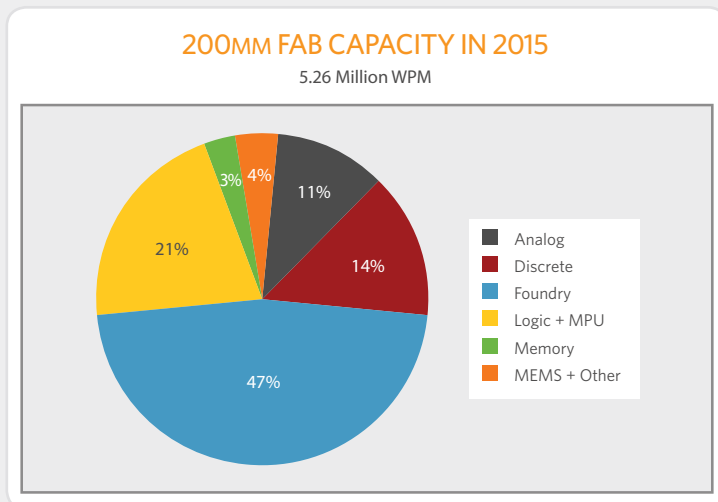


Figure 3. Production of analog devices will account for nearly half of all 200mm production in 2015. (Source: SEMI)

A SEMI report on secondary equipment issued earlier this year estimates there are about four hundred 150mm and 200mm fabs in operation around the globe, representing about 40% of the industry's total capacity. Only 10–20 fabs are expected to shut down through 2018, said SEMI's Tracy. "Sixteen 200mm fabs are operating in China, a rapidly expanding region for 200mm investments," he added. [See related article on page 32 of this issue.]

SWITCHING TO 300MM IS NOT EASY

Semico's Itow noted several MEMS manufacturers have recently moved from 150mm wafers to 200mm fabs. MEMS are not going to 300mm for a long, long time," she said.

But the picture is less clear for other parts, particularly high-volume analog and communications ICs. Also, while power discretes with thick films are currently limited

largely to 200mm wafers, some power management ICs with a bipolar-CMOS-DMOS architecture are being switched to 300mm wafers at some high-volume manufacturers.

Lineback said most of the O-S-D companies he tracks are using processes that currently "may not work on 300mm. They use thick films, advanced deep RIE, wafer bonding, and quite a few other process steps that play a bigger role. Overall, 200mm can serve a lot of the O-S-D applications for a long time."

Itow, however, said many companies are actively studying a move to 300mm wafers. "Companies are all doing their own analyses to figure out how long they can stay on 200mm. All it takes is one major competitor to make a move and show they can be more efficient on 300mm. It may not happen overnight. But that does limit the price of 200mm tools, which can't go up to where it would create a higher cost curve than 300mm production," she added.

The shortage of some used tools raises the question, will foundries and IDMs begin moving production to 300mm wafers if they can't buy more used 200mm equipment?

Karczewski, the Macquarie executive, said, "It is a big decision to switch to 300mm tools, and we have seen a limited audience to date. Companies will stay with 200mm tools for the most part."

"What we are seeing is more companies trying to get more throughput and adding capacity to their existing 200mm fabs," he said, adding that OEMs such as Applied are selling capacity and other improvement packages for their existing tools.

AGS's Cummings noted, "Although we're selling legacy equipment, we're continuing aggressive development programs to improve the tool performance, and develop entirely new 200mm processes and materials as part of our focus on precision materials engineering. Our new Applied Vita controller, for example, offers advanced control and monitoring capabilities that bring the system up to modern levels of performance. It includes a much more powerful processor, flash memory and USB ports, and enables the advanced monitoring, analytical and control capabilities needed to help fabs achieve new, critical productivity goals."

Cummings also said Applied Materials has revamped its own 200mm manufacturing operation.

"Since the first quarter of 2014, our competitiveness has improved a great deal in terms of lead times, cost and pricing. We intentionally decided to compete not just on technology, but also on the commodity or capacity buys that we had not addressed significantly in the past," Cummings said.



DEMAND FOR 200mm TOOLS OUTSTRIPS SUPPLY

EQUIPMENT IS “MUCH PRICIER”

Cody Harlow, a director at the AGS manufacturing operation in Austin, Texas, said the price of used cores has gone up sharply over the past year—that is, when those used cores are available at all. Earlier this year Harlow went to the Semicon Korea trade show, where he normally would be able to buy 15 or more used cores for refurbishment back in Austin. This year, he came back empty handed. At Semicon China in March, the story was similar.

“Some companies with available cores said they were going to hang on to them for another six months because they believe prices will keep going up,” Harlow said. The result is that “there’s less used equipment available, and it is much pricier; it has effectively doubled in the last six months.”

Harlow said Applied Materials has been able to buy multiple 200mm cores coming off the market in the past few years. That stockpile, and continued purchases from chipmakers, inventory holders and brokers, is what gives Applied’s technicians the opportunity to take used cores and add new parts, brand-new chambers, and upgrades such as the new Vita controller.

But what happens if the availability of used cores dries up completely? “That is a different paradigm, a real game changer. We are already there with epi, and it will stay that way until someone releases them,” Cummings said.

Harlow also sees a shift toward new 200mm equipment, with the industry “approaching a crossover point, where it is cheaper to build new than to chase these escalating prices for used cores.”



Cody Harlow, Applied Materials director of AGS manufacturing operations at the company’s Austin, Texas, facility.

A LONG CYCLE FOR 200mm?

Karczewski said over his 23 years in the industry he has found that sharp upturns such as the current one for 200mm tools are, unfortunately, as common as sharp downturns. He pointed to the aftermath of the Internet stock bubble in 2000, and the 2008–09 financial crisis downturn as examples. “Another financial crisis, war in the Middle East, or a broad parts oversupply, could all potentially trigger another downturn,” he added.

Cummings also is bracing for the next downturn. “I have been at Applied a little over 20 years, and I have seen the upturns and downturns. But 200mm is an interesting space. Other wafer sizes have dropped off, but 200mm is seeing a whole revival, a second life cycle.

“Take the new iPhone 6 Plus as an example. Some 75% of its chips are made on 200mm wafers, including 16 MEMS, A/D converters, power management, and other chips that don’t require super-small transistors,” he said.

“A lot of people think this upturn will last forever. I do believe it will last this year, and another year after that. It does seem that with such broad demand, and so many products made on 200mm, that we are in a different situation,” Cummings said.

Mike Rosa, director of strategy and technical marketing for 200mm products at Applied Materials, says that although smartphones continue to dominate consumption of devices built on 200mm, he also sees enough

200MM FOUNDRY CAPACITY IN 2015 & 2016

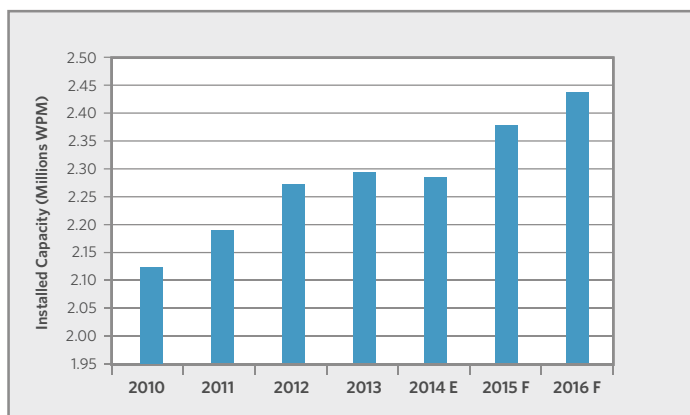


Figure 4. Foundries are ramping up 200mm capacity as demand from the Internet of Things market picks up. (Source: SEMI)



Mike Rosa, PhD, director of strategy and technical marketing for 200mm products at Applied Materials.

new technologies emerging to sustain extended demand.

"200mm is a house built on many stilts," he said, with automotive and consumer applications and now wearables and the looming IoT sector further driving the need for the myriad devices already being built on 200mm equipment. "Power ICs, MEMS-based sensors, and analog and mixed signal devices are all enjoying growth, and promise to be important sources of new demand."

Gartner Inc. analyst Bob Johnson predicts that in 2020, more than 8 billion connected things will be shipped worldwide, containing 35 billion semiconductor devices requiring production of 4.5 million wafers.

Tom Salmon, director of global member services and standards at SEMI, said, "Not all of the IoT opportunities will be done on 200mm. Some of the microcontrollers or RF devices may be done on leading-edge technologies. But with the IoT adoption coming early to industrial and automotive, we foresee a big pickup, one that will drive 200mm demand for a long time."

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SMARTPHONES AND CHINA: TIPPING POINT?



The majority of all smartphone device content consists of chips made on legacy equipment, so the implications for 200mm manufacturing are significant. Applied Materials' Mike Rosa said the worldwide smartphone market is at "a tipping point in 2015, in which more than half of all smartphone sales will be in China."

This comes at the same time that many Chinese semiconductor firms are targeting lower-cost smartphones and IoT applications. At the 2015 Semicon China show in Shanghai, Rosa said he attended several presentations where Chinese speakers discussed the need for 200mm equipment.

"Their main message is 'we have a huge market, and huge government backing over the next ten years,'" Rosa said, noting there are more than 100 smartphone makers in China, all of them needing chips made on 200mm wafers. [See related article "China: Investment Fever Kicks IC Industry Into High Gear" on page 32 of this issue.]

"If China's domestic smartphone makers continue to see increasing sales, it is likely to result in new 200mm fabs in China," he added. China's government has set a goal of domestic chip companies supplying 40% of China's domestic IC consumption by 2020.

Going forward, if Chinese phone vendors are supplied mainly by the established IC and MEMS vendors, it would result in incremental additions of equipment to increase capacity at existing fabs around the world. But if Chinese IC and sensor companies spring up to supply smartphone component demand in China, whole new 200mm fabs may be built there, adding significantly to worldwide equipment sales, Rosa said.

He noted that China's policy to supply itself also extends to equipment. "None of us should think that when China ramps up, that we will all just walk in and sell them tools. There already are existing domestic equipment manufacturers. And China's government is saying, 'Buy domestically unless you absolutely can't get what you need in China.'"

DEPLOYING MULTIVARIATE ANALYSIS TO IMPROVE FAB PRODUCTIVITY



Multivariate data analysis is a powerful statistical methodology made possible in recent years by the availability of increased computing power. The technique takes into account multiple variables simultaneously, enabling the study of complex data sets that are beyond the capabilities of traditional univariate analysis.

**BY
GARY DAGASTINE**

Multivariate data analysis shifts the focus from individual factors to relationships among variables, identifies root causes and indirect effects, and allows for the use of predefined models and data templates to speed the analysis.

Applied Materials is now offering proprietary multivariate data analysis as part of its FabVantage consulting solutions,

which help customers increase overall fab efficiency and output. Using multivariate analysis, FabVantage consultants can identify root causes for factory-level issues such as capacity shortages, long cycle times, high wafer costs, line imbalances, high levels of work-in-process (WIP), and high variability, among others.

FAB PRODUCTIVITY PRACTICE: FOCUSED ON THE BIG PICTURE

Applied's FabVantage team begins each engagement with a top-down, data-driven assessment to identify issues that are having major impacts on fab productivity. A roadmap for improvement is created based upon comparisons of the customer's data with benchmarks and best practices in the Applied Materials knowledge base. Probable causes for underlying performance gaps are then outlined, and a proposal is presented to the customer.

Part of the FabVantage Fab Productivity Practice toolkit for multivariate analysis is an internal fab analyzer built on the same platform as Applied's APF Real-Time Dispatcher and Reporter—software tools that help manufacturers develop customized rules and improve dispatching decisions.

Applied's fab analyzer contains many models built and tested based on Applied's global experience, so consultants can move forward more quickly to help customers. An example using the fab analyzer is shown in figure 1.

The company's multivariate analysis tools not only help pinpoint the root causes of the problem, they also enable consultants to create a list of priorities so that FabVantage engineers can develop an implementation plan to quickly deliver major results to customers, often within a 3- to 6-month timeframe.

RESOLVING BOTTLENECKS

The FabVantage Consulting Group is frequently engaged to help customers find ways to squeeze more capacity out of their existing fabs by increasing throughput, which can eliminate or defer the need for sizeable capital investments.

"When we and the customer work together in a deep technical collaboration, we usually uncover cost-effective ways to increase overall fab capacity and throughput," said Productivity Practice Manager Haim Albalak. "One very effective way to create this new capacity is through better management of the WIP flow."

One example of this approach is to optimize product sequencing to reduce changeovers and increase throughput. In one instance, FabVantage consultants performed an analysis that examined the time distribution of repeating the same recipe within one of the customer's ion implant tool groups. The analysis revealed a high frequency of repetition of the same recipe within a short window of time (less than two hours). This meant there was a potential opportunity to reduce setup time and improve tool output (see figure 2).

The next step was to find the optimal cascading level by analyzing the relationship between the cascade size and the lot cycle time. The optimal location is the point on the curve that represents the minimum lot cycle time (see figure 3).

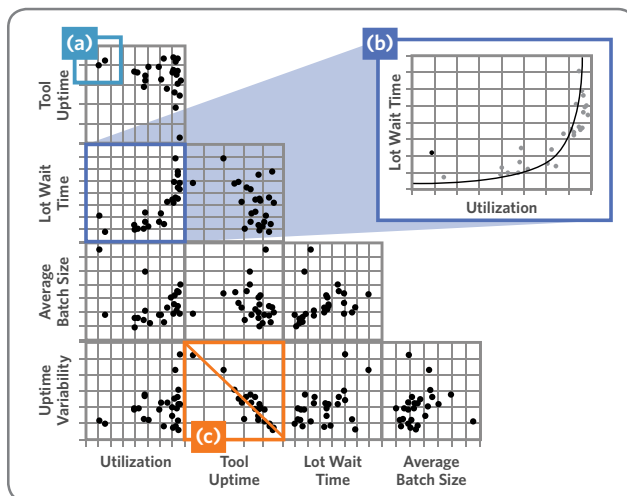


Figure 1. The figure shows the results of a multivariate statistical analysis of the performance of a group of tools. It illustrates the ability of the technique to uncover the relationships among different variables that impact cycle time. The area highlighted in (a) shows that some tools with high uptime aren't being used, even though (b) tells us that cycle time (i.e. "lot wait time") is strongly driven by tool utilization. Also, (c) shows that among tools having low uptime, there is a high variability in uptime.

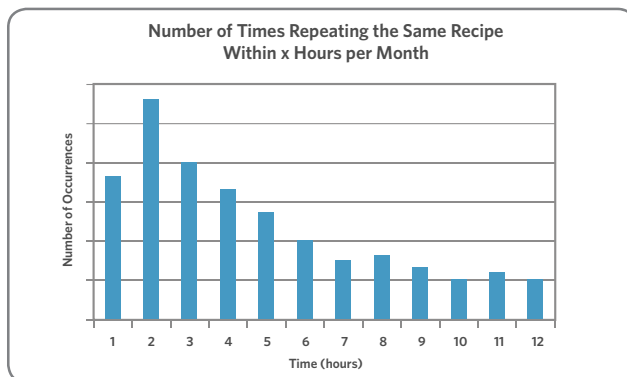


Figure 2. Analyzing recipe repetition within a 2-hour time window revealed an opportunity to reduce setup time and improve tool output by increasing the cascading level.

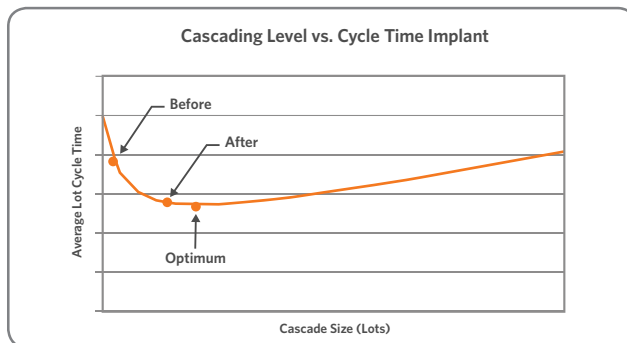


Figure 3. Finding the optimum cascading level to achieve minimum cycle time at one customer site. The figure shows the relationship between the cascade size and the lot cycle time. The optimal location is the point on the curve that represents the minimum lot cycle time.



DEPLOYING MULTIVARIATE ANALYSIS TO IMPROVE FAB PRODUCTIVITY

As a result of this analysis, the customer's Real-Time Dispatching (RTD) rule was updated to support the new cascading target (see figure 4).

Implementing the new dispatching rule improved the cascading level, reduced lot cycle time, and increased tool output by 5%.

REDUCING CYCLE TIME

Cycle time is another critical element of fab performance because it determines how quickly manufacturers can get products to market. In addition, variability in cycle time impacts a manufacturer's ability to predict the timing of production, and therefore their ability to meet on-time delivery commitments.

Tool dedication is a major factor that influences fab cycle time and throughput performance. In many cases the official tool qualification matrix that indicates which recipe is qualified to run on each tool does not reflect the actual dedication level. Often, the tool dedication is much higher.

Analyzing fab historical data with the Applied fab analyzer allows FabVantage consultants to determine the real tool dedication level based on the actual number of tools that run each product step (see figure 5).

Using multivariate analysis to evaluate the relationship in the fab between tool dedication and the lot waiting time (queue time) has revealed a strong correlation: when the lot has fewer tools capable of running it, the lot waiting time is higher (see figure 6).

In one instance, based on the analysis in figure 6, a roadmap to reduce factory cycle time by 20% was developed (shown schematically in figure 7). The primary strategy for decreasing the cycle time was to reduce the impact of tool dedications on WIP movement through the line.

Minimizing the impact of tool dedication was accomplished in two ways. The first was to improve tool matching and increase the number of tools that are qualified to run the product steps with the highest wait times. The second was to modify the dispatching rules in RTD to reduce the probability that tools qualified to run fewer product steps would run out of lots they are capable of running.

IMPROVED TOOL AND FAB PERFORMANCE

Applied Materials has demonstrated that by deploying advanced multivariate analysis techniques, both the performance of Applied tools in the fab and the overall output of the fab itself can be improved.

Our modelling methods have helped customers improve scheduling, shift bottlenecks, reduce cycle time and cycle time variability, and increase the throughput of the fab. For many capacity-constrained customers, these analyses often have helped increase the output of their fabs with minimal capital investment.

For additional information, contact avi_edelstein@amat.com

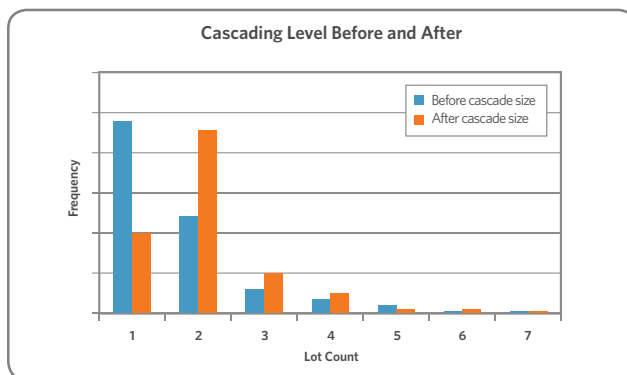


Figure 4. Improved cascading level as a result of changing the lot dispatching rules.

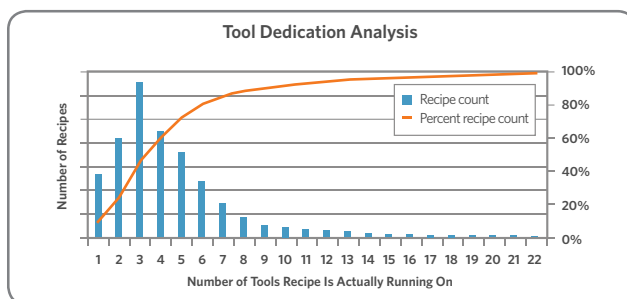


Figure 5. Tool dedication analysis using Applied's fab analyzer.

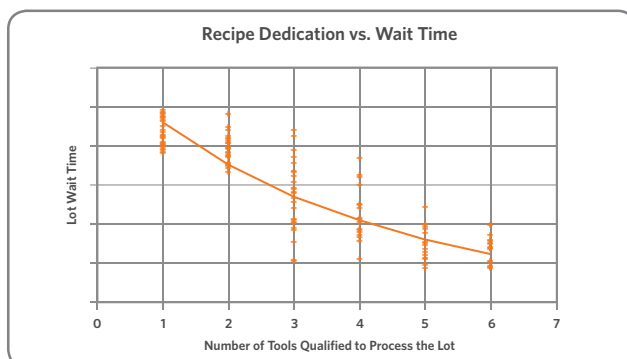


Figure 6. FabVantage consultants used multivariate analysis to uncover a strong correlation between the number of tools that were actually dedicated to a particular recipe in a fab and resulting lot wait time (queue time).

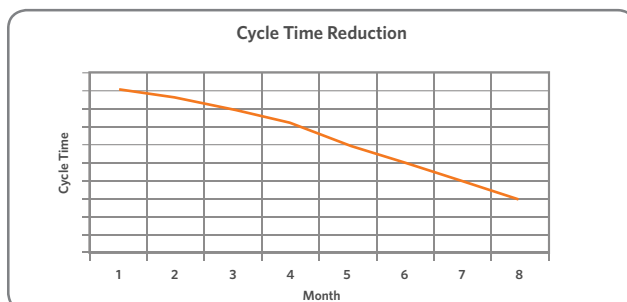


Figure 7. Fab cycle time reduction roadmap based on improving tool dedication.

CASE STUDY

Wafer Scrap Reduction
in a 300mm Logic Foundry

Device manufacturers face ongoing challenges to control variables, maintain productivity and improve their operations. Tool audits that benchmark a tool to best-in-class data, combined with sophisticated data analytics, can help manufacturers meet these challenges. Here is how Applied Materials used these methods to help a customer dramatically reduce wafer scrap from one tool.



BY
DONG CHAE,
PAUL TURNBULL
AND MARINE ZHANG

CHALLENGE

One of our foundry customers experienced a high scrap rate in gate stack fabrication, caused by a group of Applied Materials Centura tools equipped with ISSG, DPN Plus and PNA chambers. This tool group had one of the fab's highest scrap rates, and excessive parts replacement costs were required as a result. The customer asked the Applied Materials FabVantage Consulting Group to identify solutions to cut scrap by half.

SOLUTIONS

- A FabVantage tool assessment identified root causes using data analytics to speed diagnostics. As a result, faulty parts were replaced, equipment settings were set to their BKM values, recipe adjustments were made, and correct PM procedures were implemented.

IMPACT

- The customer exceeded its goal. Wafer scrap from the tool group was reduced to <0.2% and spending on parts was reduced by 4x. In fact, a tool in the group went from being one of the fab's worst-performing tools to being the very best one.

A 300mm logic foundry was experiencing significant levels of wafer scrapping from a key gate stack fabrication tool set. The tools were Applied Materials Centura systems equipped with in situ steam-generated oxide (ISSG), decoupled plasma nitridation (DPNPlus) and post-nitridation anneal (PNA) chambers.

The problem manifested itself as a dense streak of particles on the processed wafers (see figure 1). The customer was unable to identify the root causes, and hired Applied Materials' FabVantage Consulting Group to perform an assessment.

Applied's FabVantage consultants combine extensive fab and tool expertise

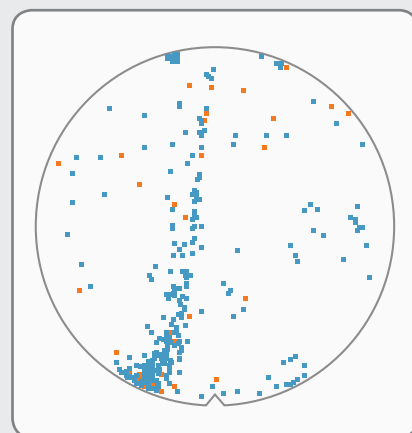


Figure 1. Typical pattern of particle contamination seen on 0.6% of the processed wafers from one Centura tool at a 300mm logic foundry prior to a FabVantage tool audit.

CASE STUDY

Wafer Scrap Reduction
in a 300mm Logic Foundry

with state-of-the-art modeling and analysis tools. They engage in collaborative relationships with customers to help solve some of the industry's most difficult manufacturing challenges.

Projects begin with a discovery session to identify key customer goals and challenges. Then a benchmarking process is performed to compare customer data with best-in-class data from Applied's knowledge base. Subsequently, a formal assessment is conducted to define the problem and develop a strategy to achieve improvements in targeted areas.

FabVantage consultants conducted a comprehensive hardware and process audit at the foundry, which included:

- Comparison of the product recipe to the initial Applied Materials recipe
- An audit of the fab's actual preventive maintenance (PM) procedure versus Applied's recommended PM procedure
- Checks of the settings of the equipment constants

- Comparisons of the parts being used on the tool with those on Applied's recommended parts lists

The FabVantage team used data analytics to quickly pinpoint the causes of tool misprocessing. Analytics tools included Applied's E3 automation and equipment engineering system; a knowledge base of sensor and event collection plans for each chamber; and data visualization routines.

The team also performed sensor trace analysis to compare sensor values on good chambers versus the corresponding sensor values on bad chambers, to identify obvious abnormalities.

A total of 48 issues were identified. Several were related to damaged or non-best-known-method (BKM) parts, including a worn non-BKM throttling gate valve with a damaged coating; a scratched robot blade that was not levelled; a chipped quartz ring; a single-wafer loadlock (SWLL) with dirty O-rings and particles in the loadlock; dirty lift pin tubes; worn pads on

the tips of the factory interface robot blades; and scratched reflector plates.

In addition, sensor data visualization revealed the following issues: excessive pressure oscillation; N_2 overshoot in the DPN chamber; timing variations for pressure stabilization across chambers; and varying pump-down times across different chambers.

Finally, the FabVantage team's audit showed that recommended PM procedures had not been followed.

DPN CHAMBER PRESSURE INSTABILITY WAS KEY

Key among the findings was that the DPN chamber was unable to maintain a stable pressure. Sensor trace analysis identified pressure undershoot and spiking, as shown in Figures 2a and 2b.

A faulty pressure control valve caused the DPN chamber pressure to overshoot. Additionally, when RF power was turned on, the chamber pressure and foreline pressure oscillated because the throttling gate valve was unable to maintain a stable pressure.

The particle streak shown in figure 1 typically might be assumed to be the result of faulty wafer placement. That normally would be a robot or local center

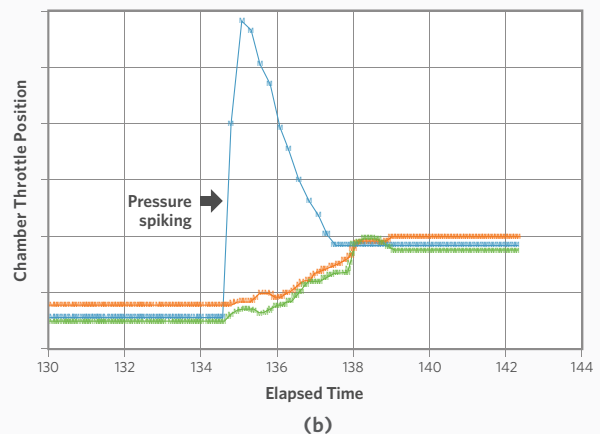
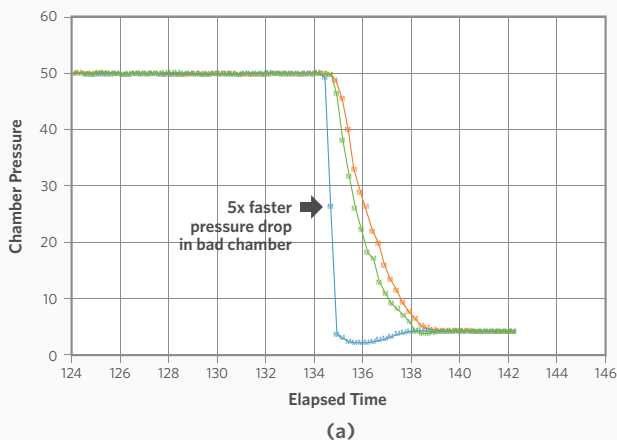


Figure 2. Graphs showing DPN chamber pressure instability in the Applied Centura tool group. Figure 2a shows a 5x faster pressure drop in one chamber, which likely caused wafers to pop. Figure 2b shows pressure spiking due to faulty pressure control and throttling gate valves.

finder (LCF) issue, but that was not the case here. Instead, the pressure oscillation caused the wafer to pop, which in turn led the LCF to react by recalculating as though there had been a wafer placement error.

This issue was discovered by overlaying the pressure oscillation data with the LCF correction distance, and observing that the LCF started to correct at the same time the pressure spiked or dropped.

VALVES REPLACED

Once the pressure control valve and throttling gate valve were replaced, the wafer popping stopped and the LCF stopped recalculating. Figure 3 shows the LCF distance before and after replacement of the valves. Figure 4 shows DPN chamber pressure stability before and after replacement of the valves.

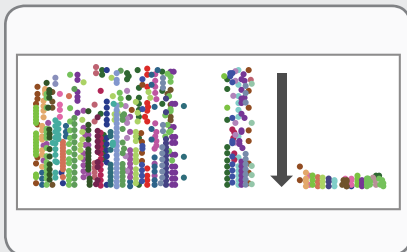


Figure 3. Data plot shows the LCF correction distance before and after replacement of faulty pressure control and throttling gate valves. The data to the left of the arrow shows a large, varying LCF distance prior to replacement of the faulty valves. Data to the right of the arrow shows a short, uniform LCF distance after the valves were replaced.

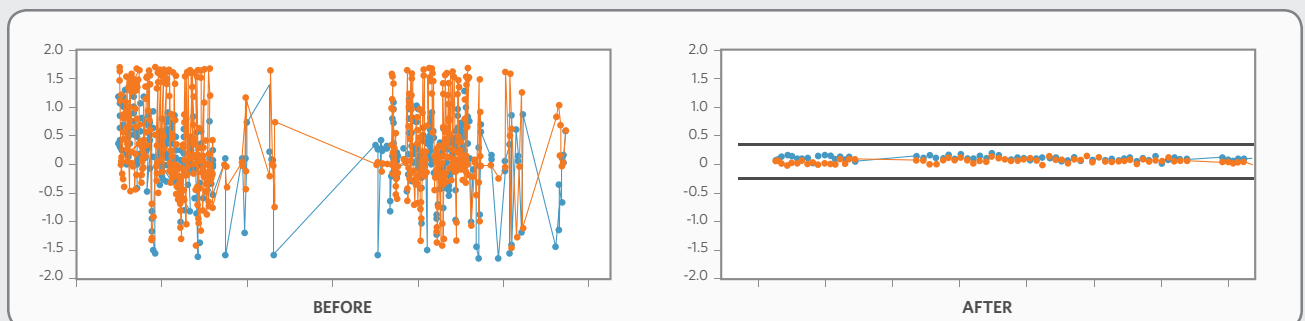


Figure 4. DPN chamber pressure before and after replacement of faulty pressure control and throttling gate valves, showing a much more stable environment after they were replaced.

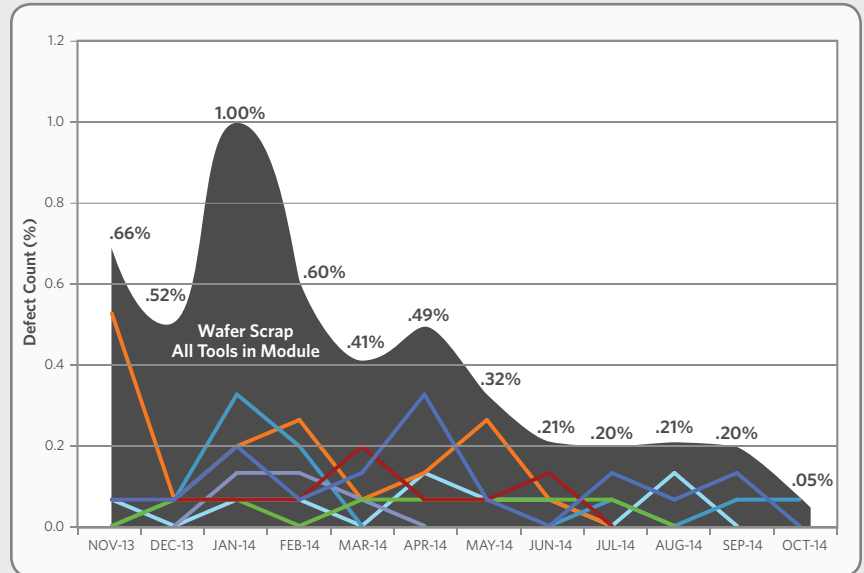


Figure 5. The monthly defect count trended downward after implementation of all Applied FabVantage recommendations. Each color represents a different Applied Centura gate stack tool.

The combination of state-of-the-art FabVantage data analytics, supported by information from the Applied knowledge base, was instrumental in the rapid troubleshooting of the pressure control issue.

The knowledge base enabled the FabVantage consultants to quickly generate data collection plans and identify priority sensors. The LCF position does not have a sensor associated with it, so the team devised a data transformation to compute the LCF correction distance.

For easy visual identification of problems, the team wrote scripts to create

charts that allow values from multiple sensors and chambers to be overlaid.

DEFECTS AND SCRAP REDUCED

After implementing all FabVantage recommendations, defect counts fell on all tools in the gate stack module, as shown in figure 5. Wafer scrap fell to <0.2%, substantially exceeding the customer's goal. As an additional benefit, customer spending on parts was reduced by 4x.

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CHINA:

INVESTMENT FEVER
KICKS IC INDUSTRY
INTO HIGH GEAR

BY ADELE HARS

The chip industry in China is facing a dilemma. While the nation currently consumes about half the world's roughly US \$350 billion in chips,^[1] fabs in China only account for 2.5% of worldwide IC revenue. Chips are China's biggest import, surpassing even oil.

China's chip industry is still posting double-digit growth, so the country's leaders have decided to seize the moment and set their country on course to become a chip manufacturing powerhouse. They've tried to boost domestic manufacturing before, but with limited success. This time they have again set ambitious goals and offered up significant seed money, but it's now up to the marketplace to make it happen. And the marketplace is responding with gusto.

According to SEMI estimates in January 2015, total Chinese government (central plus local) funding will reach US \$100 billion over the next 5 to 10 years, while McKinsey & Co., in August 2014, suggested that national and provincial funds combined could reach US \$170 billion over the same time period. Officially called the National Industry Investment Fund, it's prompting the creation of a host of new VC funds and matching investments, and the bolstering of existing funds.

Which is why everybody is calling it the best time the industry's ever seen. In his talk to a packed hall at Semicon China 2015, Handel Jones, China expert and CEO of IBS, called it a once-in-a-lifetime opportunity.

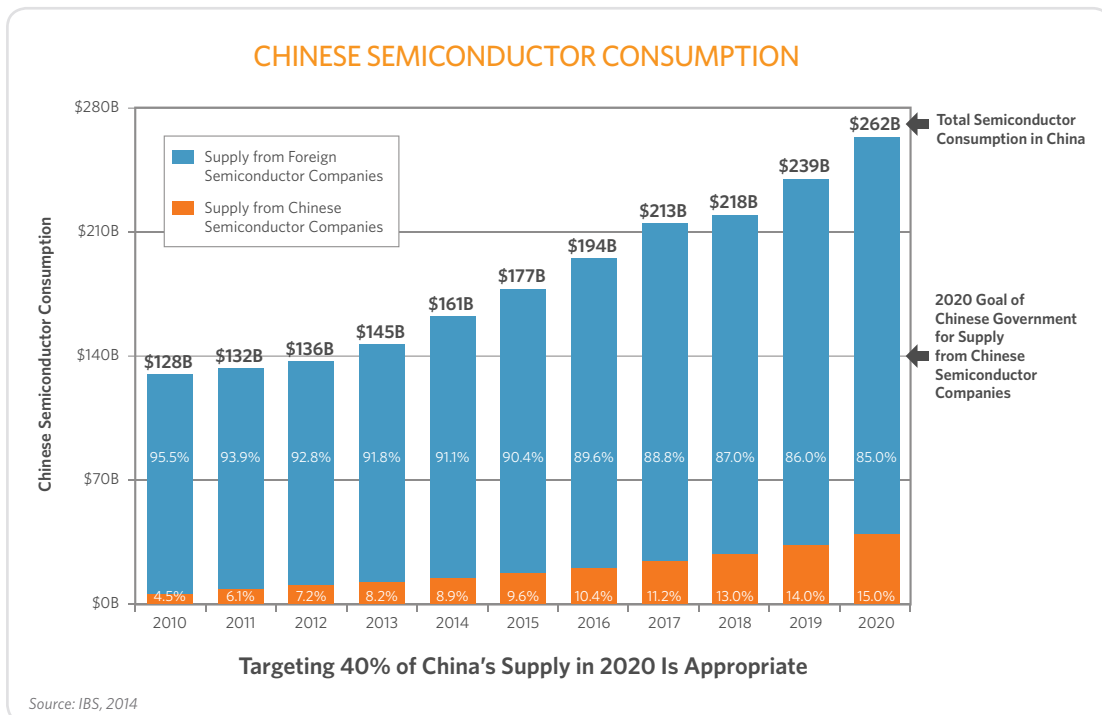
THE GUIDELINES

In June 2014, the Chinese State Council issued the *National Program to Promote the IC Industry Development*, which provides the guidelines that industry is expected to use.

The guidelines begin by identifying the problems that impeded past efforts. Primary among those are financial bottlenecks, risk aversion, a shortage of key talent, general fragmentation, and holes in the supply chain.

The development goals outlined are as follows:

- For 2015, the guidelines call for the establishment of platforms for financing and policy; moving 32/28nm to volume across the spectrum of production, packaging and test; and investment in additional equipment for 65/45nm, world-class design, advanced technologies and 300mm wafers.
- By 2020, the technology gap should be narrowed, 20% CAGR should be sustained, and 16/14nm should be in production.
- By 2030, China should have tier 1 IC companies.



CHINA:

INVESTMENT FEVER KICKS IC INDUSTRY INTO HIGH GEAR

It is important to note that economic prowess is not the only driving force here. In the wake of recent security scandals, the program also notes that China needs a strong domestic chip industry to ensure security.

A task force was created, including members from key ministries in IT, science and technology, finance, and national development. But to ensure that the policy implementation is market-driven and focused, the task force also includes about a dozen industry leaders.

THE FUND

October 2014 marked the establishment of the National Industry Investment Fund. According to SEMI, the first round of ordinary share-raising was completed at the end of the year, having raised 98.72 billion RMB (US \$15.9 billion). Another round in the first quarter of 2015 raised the total to almost 140 billion RMB (US \$22.5 billion).



Xi Wang, academician and director general of the Shanghai Institute of Microsystem and Information Technology (SIMIT) / Chinese Academy of Sciences (CAS).

The cities and regions with major tech centers also raised funds. In initial rounds, Beijing, for example, raised almost 30 billion RMB (US \$5 billion) to support manufacturing and equipment, as well as design and packaging. A Shanghai fund raised 10 billion RMB (US \$1.6 billion).

Even so, it's not enough, said Dr. Xi Wang, director general of the SIMIT institute, the Shanghai branch of the Chinese Academy of Sciences (CAS) and special advisor to the central government in Beijing. "It's a critical moment," he says, "and we need momentum to expand capacity."

There are a hundred CAS institutes in China, with a budget of over 42 billion RMB (roughly US \$7 billion). In previous government attempts to bolster the chip manufacturing industry, the institutes were given the lead. While they gave R&D a much-needed boost and created a strong academic base, they alone could not create the necessary momentum.

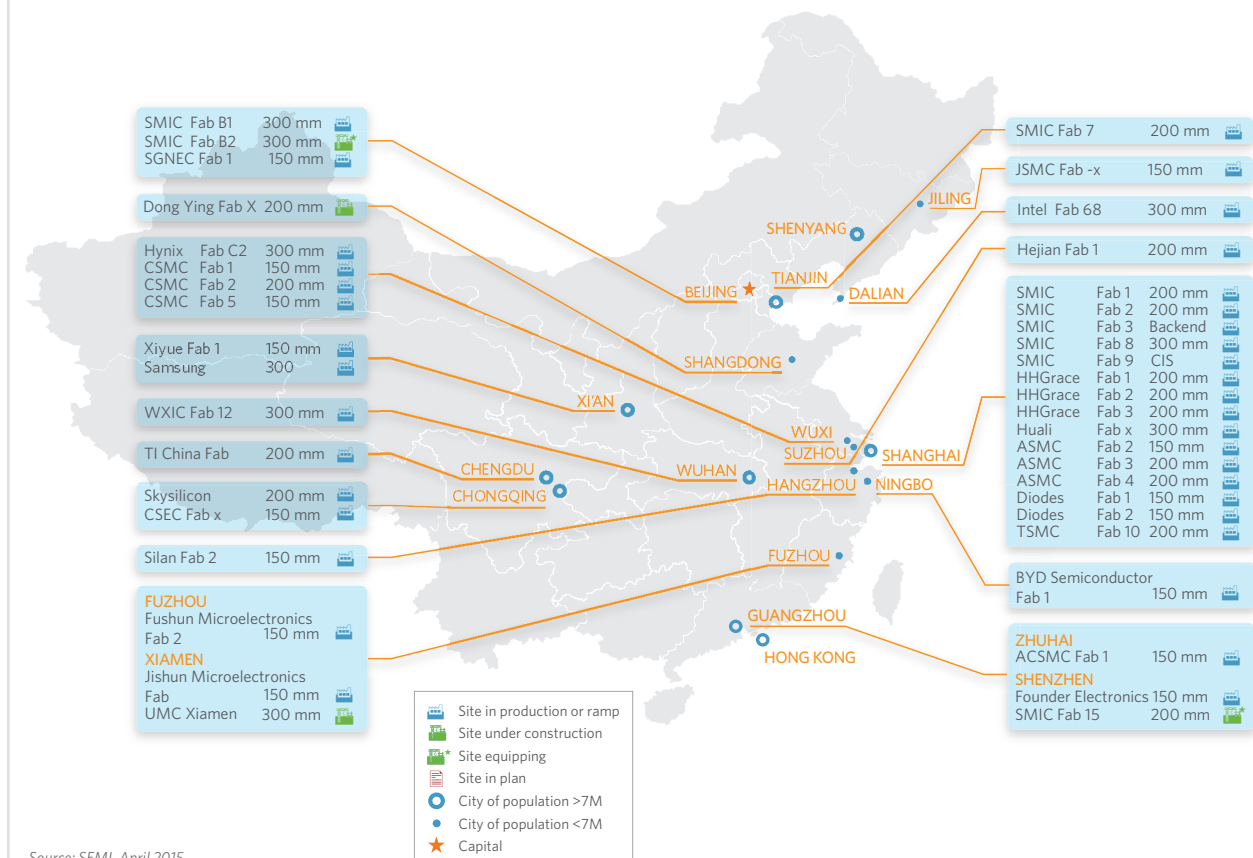
This time, says Dr. Wang, things will be different. "Now in the IoT era, China is a big market. It's totally different from what it was ten years ago. There is huge demand in China, and Chinese vendors will be successful."

CAS and the institutes still have a very important mission to fulfill, however. They are charged with both pure scientific discovery and transferring technology to industry. SIMIT's SITRI institute in Shanghai, for example, is now completing the installation of an 8-inch R&D line that enables researchers to hand off More-than-Moore developments in power, RF, sensors and MEMS directly to industrial partners worldwide.

The automotive IC market is seen as a major opportunity, too. In 2010, China passed the US to become the world's largest market for automobiles. While the Chinese auto industry is no longer posting the double-digit growth of a few years ago, relatively speaking it's still growing more quickly than the rest of the world.

Charles Chesbrough, senior principal economist at IHS Automotive, told *Nanochip Fab Solutions* that the auto industry in China is expected to grow at a 4.1% annual rate from 2015 through 2020. "The rest of the world is expected to grow at a 2% annual rate through 2020, so China will be growing at near twice the rate," he notes. This combined with chips per vehicle increasing from 800 to 1000 (Strategy Analytics, 2015) in that same time frame makes for a perfect storm.

LOCATIONS OF CURRENT SEMICONDUCTOR MANUFACTURING OPERATIONS IN CHINA



Source: SEMI, April 2015

THE MAP

China is the world's fourth largest country in terms of area, and the largest in terms of population. So it is perhaps no surprise that there are multiple tech centers.

Shanghai is often considered China's Silicon Valley. Fiercely modern, it is home to more than 20 fabs and soon a major new 11 km² (4+ square miles) industrial park in the Pudong district near the airport. With a 30 billion RMB (US \$4.8 billion) fund, the developers say they have already signed up two chip companies and many suppliers. They also promise it will have affordable housing, good schools, and since it's on the ocean, clean air.

Beijing, seat of the central government and steeped in thousands of years of history, is nonetheless a hotbed of fabless start-ups. SMIC's current and planned 300mm fabs are there, among others. They're ready with 28nm this year, and have demonstrated functional FinFETs. Three years of consecutive profitability have helped.



CHINA:

INVESTMENT FEVER KICKS IC INDUSTRY INTO HIGH GEAR

Xi'an is home to over 70 universities and over 800 research institutes, national labs, and centers for technical research and industrial testing.

Samsung chose it for a 300mm memory fab, and in 2007, Applied Materials opened a Global Development Center there that provides worldwide engineering and software support.

In addition, the two Hynix-Numonyx 300mm fabs are in Wuxi, and Intel's 300mm fab is in Dalian. However, of the roughly 50 fabs around the country, about 40% are 200mm and 40% are 150mm. Overall, China's equipment spending grew by 30% in 2014. But with so much 150mm and 200mm legacy equipment, SEMI indicates that the refurbishment market there is a very active business. (See related article, "Demand for 200mm Tools Outstrips Supply" on page 20 of this issue.)

Roger Chang, country president of Applied Materials China, noted, "China's IC industry is developing rapidly. Much can be done on the part of equipment manufacturers who are ready to contribute to growth in this industry."

Dr. Mike Rosa, director of strategy and technical marketing for 200mm products at Applied, added that the company's Xi'an-based development center is a key asset in the region for supporting customers' needs in semiconductor equipment engineering and field services, as well as in factory automation software, process diagnostics and control, and equipment engineering. "With so many new and existing companies entering the More-than-Moore segments, it is important that customers have a development partner who can demonstrate key enabling technologies locally and react quickly to their development needs."

INVESTMENT FEVER

The national fund's goal of attracting large enterprises, financial institutions and talented people has generated an enormous degree of investment fever. Ex-pats are returning to China in droves to create new businesses and manage existing ones. The real estate boom is over, freeing up new money from private sources. Money's coming in from abroad, too. Intel recently made a \$1.5 billion investment in Tsinghua Unigroup, which just bought two of China's largest fabless companies.

In three full days of presentations at Semicon China 2015, almost no one missed an opportunity to celebrate the China boom. Mergers and acquisitions (M&A) are viewed as the best way to fill holes in expertise and resources quickly, as the rush is on to meet the goals set out in the national guidelines.



Tech Investment Forum, Semicon China 2015.



A Chinese New Year billboard in the Shanghai Metro.

Two pieces of advice kept coming through: one plus one has to equal more than two; and the main reason to acquire a company is to get their top talent, so it's critical to keep them happy.

In fact, at the event's Tech Investment Forum, a managing director of Goldman Sachs explained the dos and don'ts of a successful acquisition during a standing-room-only presentation. China is now #2 in M&A, just behind the US, he said, and 2015 is expected to be a record-breaking year.

Although a lot of the activity until now has been domestic (especially consolidating the huge but fragmented design community), and IPOs in Hong Kong are gaining in popularity, there's a definite shift to Chinese companies buying outside the country. Chinese companies are being encouraged to take a perspective that is at once Chinese, international and market-oriented.

In glowing terms, the CEO of JCET described his company's acquisition of STATS ChipPack, creating a new #3 in device packaging. The national fund, while not directly investing in the transaction, was effectively leveraged, he said.

Dr. Xi Wang is also very enthusiastic about the new investment era. Given his status and experience in the industry, he knows virtually everyone. He especially likes matching promising companies with funding. "I like to do that—I have the vision," he says.

One of several companies he himself has created over the years is Simgui, China's wafer leader. Initially founded in 2001 to make SOI wafers for power and MEMS, the company extended its business to 300mm wafers. They now have a partnership with Soitec for wafers for RF-SOI. Dr. Wang posits that moving to FD-SOI could be an option for certain Chinese fabs, because it would enable them to quickly move into a leadership position. However, he cautions, it's the market that will decide this time.

And that will make all the difference.

Adele Hars is a writer and director of High Tech International, based in Paris, France.

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^[1] *World Semiconductor Trade Statistics, 2015*



IN



CELEBRATING A DECADE OF NANOCHIP

This year *Nanochip Fab Solutions* celebrates its 10th anniversary. Since our premier edition in July 2006, we've published nearly 200 articles in 19 issues (including this one), emphasizing ways to increase tool throughput, boost fab productivity, and improve yields.

Over the past decade, we've also looked at ways to reduce fab costs and environmental impacts, covered trends that shape our industry, and introduced new technologies that address complex manufacturing challenges.

As part of our 10th anniversary celebration, we decided to list our top 10 favorite *Nanochip Fab Solutions* articles. It turned out to be like asking a mom to choose her favorite child—because we love them all, but for different reasons! With the help of frequent contributor Dave Lammers, however, we did pare down the list. Here, in random order, are 10 favorite stories from *Nanochip Fab Solutions*' first decade.

VOLUME 2/
ISSUE 2

DECEMBER 2007

"New Strategies for Fab Productivity"

Underscoring the growing trends toward consumer electronics, industry consolidation and the contemplated shift to 450mm, this story took a wide-angle view of fab productivity and examined ways to minimize variability and non-productive time in mainstream 300mm fabs to achieve high productivity gains at lower risk.

VOLUME 8/
ISSUE 2

DECEMBER 2013

"Fabs in the Internet of Things Era"

Not only did this article explore one of today's most important topics—the IoT—and its game-changing potential, it also looked at how managing "big data" and attendant security concerns are among the biggest challenges facing manufacturers who want to reap the benefits of a connected fab. In fact, we think this entire issue of *Nanochip Fab Solutions* ranks among our very best, packed with news, trends and timely information.

VOLUME 8/
ISSUE 1

JULY 2013

"Advanced Service Detects Arcing, Boosts Yield"

This technical discussion of our development efforts in arc detection in PVD chambers sparked unprecedented customer interest because of the potential to increase tool uptime and reduce wafer scrap and yield loss.

VOLUME 7/
ISSUE 1

JULY 2012

"Rev Up Your Engines"

In this entertaining, informative, and popular article, the efforts of AGS engineering teams to apply new materials, innovative surface technologies and design improvements to 200- and 300mm process chambers were compared to restoring a vintage automobile.

VOLUME 10/
ISSUE 1

JULY 2015

“China: Investment Fever Kicks IC Industry into High Gear”

In what may well be a precursor to stories we'll cover over the next few years, guest editor Adele Hars offers a compelling look at the emerging semiconductor manufacturing industry in China, including insights from industry watchers and Chinese government leaders.

VOLUME 5/
ISSUE 1

JULY 2010

“MEMS Going Mainstream to Serve Consumer Markets”

Coming on the heels of introductions of Nintendo's Wii and Apple's iPhone, this article focused on consumer fascination with gesture and motion control in consumer devices, describing the bigger challenges facing MEMS manufacturers—from productivity and cost issues to the need for fast etch rates.

VOLUME 6/
ISSUE 1

JULY 2011

“Texas Instruments Reinvents Itself”

Based on interviews with TI Senior Vice President of Manufacturing Kevin Ritchie and other company executives, this article provided a fascinating look at how TI used refurbished 300mm equipment to gain a competitive advantage in the analog IC sector.

VOLUME 7/
ISSUE 1

JULY 2012

“Big Data: Too Much of a Good Thing?”

Explosive data growth in the semiconductor industry has become a major challenge, but one that is full of opportunities. This futuristic article explored how the ability to manage large data volumes and move from a reactive to a predictive state has the potential to drive significant value for Applied Materials customers.

VOLUME 7/
ISSUE 2

DECEMBER 2012

“Strong Engineering Foundation Supports Yield Improvement”

Showcasing the Applied Materials FabVantage Consulting Group, this article describes how consultants use traditional top-down methods as well as an innovative bottom-up approach to identify process issues and help customers achieve dramatic yield improvements.

VOLUME 9/
ISSUE 2

DECEMBER 2014

“New Vita Controller Demonstrates Performance on >1 Million Wafers”

With clear signs that 200mm production tools will be around for a while, this article introduces Applied's Vita controller, which brings to legacy tools much-needed analytical and control capabilities previously available only in 300mm tools. This is a story of a technology extension that really delivers for customers.

The goal of *Nanochip Fab Solutions* has been, and will continue to be, keeping customers informed about key industry trends and the latest product and service solutions from Applied. We hope that information will enable you to—as Charlie Pappis likes to say—“get ahead of the curve, whatever its direction.”

So keep reading, and contact us at nanochip_editor@amat.com to let us know what your favorite articles are. We want you to enjoy *Nanochip Fab Solutions* as much as we do!



Liz Baird
Editor-in-Chief

— If you're reading this online, please click on each title to view the full article.

If you're reading it in print, go to www.appliedmaterials.com/nanochip/nanochip-fab-solutions/july-2015.

SEMATECH: A LOOK BACK

When Sematech was folded into SUNY Polytechnic in mid-May, it brought to mind how challenging Sematech's existence has been, and how a single person—in Sematech's case, industry-legend Bob Noyce, co-inventor of the integrated circuit—can make such an outsized difference in pulling people together behind a common goal.

In the early 1980s, Japan had stunned the U.S. semiconductor industry with its quick rise in memories, having mastered two essential technologies: CMOS-based DRAMs, and lithographic equipment (steppers). Noyce went there on a personal fact-finding mission, where he observed the high quality of Japan's semiconductor manufacturing fabs. He came back home and warned Gordon Moore and others that the United States had to improve its manufacturing or face further reversals.

Noyce also wrote a personal check for \$50,000 to Larry Sumney, who was trying to get the Semiconductor Research Consortium (SRC) on its feet. He urged Sumney to use the money to pay rent and other expenses while Sumney lobbied the U.S. industry and Washington for funding.

Sematech was formed in 1988, and a Japanese assessment then gave Sematech only a 25% chance of succeeding, given American cultural propensities. Were it not for Noyce, that prognosis would have proved correct. Almost immediately, a problem arose. The 14 member companies were obligated to send assignees to Austin; however, many of those assignees were not the best talent available. One of the senior managers at Sematech in those early days much later confided that he had been instructed to make sure that none of his company's secrets leaked out.

With Sematech stumbling right out of the gate, Noyce offered to step in, becoming the organization's CEO in mid-1989. Immediately, young engineers from member companies eagerly sought out assignment to Sematech and a chance to rub shoulders with Noyce.

The U.S. Congress had agreed to put up \$100 million each year for 5 years, matching the financial contribution of the member companies. To make sure its money was being well spent, a full-time staffer from the Government Accounting Office was on site in Austin to monitor Washington's investment. And there was plenty of grumbling from members of Congress about favoring one industry over another—a short-sighted view.

Besides attracting talent and securing financial support, Noyce and the succeeding Sematech leaders faced another challenge: how to devise a research agenda that would satisfy the member companies. By 1990 most of the U.S. industry had abandoned DRAMs, and Sematech switched from running a memory process development organization and prototyping fab to a microprocessor-centric agenda. Not long after that, Micron Technology understandably withdrew, followed by LSI Logic, Motorola, and others. The comings-and-goings of Sematech member companies had begun.

Noyce once said that his main job at Sematech had little to do with technology development. His success would be judged on changing a culture in which the semiconductor companies beat up their equipment vendors on price. Sematech's main goal, Noyce said, was to engender a cultural change in which the chipmakers saw their suppliers as partners. In that sense, Noyce and Sematech put a business value on collaboration that continues in varying degrees today.

There are lessons to be learned from Sematech. One is that relying on state funding is not a good idea for research consortia that have a much broader focus. Mike Polcari, who ably served as Sematech's CEO during a period when the state of Texas gradually withdrew its support, recalled how a promised grant of \$35 million turned overnight into a loan, which had to be paid back, with interest. Little wonder that Sematech—which had helped put Austin on the map as a semiconductor technology center—decamped to Albany, New York, lured by a \$300 million investment from that state.

A second lesson is that consortia should not be seen as employment agencies. Both Texas and New York viewed Sematech as a source of local jobs, rather than as a national center to strengthen an essential technology foundation.

Add up the challenges—stable funding, attracting talent, a broad agreement on the R&D agenda, establishing trust—and Sematech's track record of successes and disappointments begins to come into better focus. Bob Noyce was a big enough man to get many of us to see the benefits of collaboration and invest in making it work—and a rare one, indeed.



Robert (Bob) Noyce

THE LAST WORD



David Lammers is an Austin-based technology journalist.



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