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Panasonic CONNECT

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VIEWPOINT

By Phil Alsop, Editor

Cautious optimism for the coming year

THE RECENT KPMG LLP and Global Semiconductor Alliance (GSA) 18th annual global semiconductor industry survey reports that industry executives have a generally positive outlook for 2023. 81% expect their company's revenue to grow during the year, with half expecting growth of more than 10%. The 'bad' news is that executives do not appear to be as optimistic this year as last. 64% believe that the industry's revenue will grow in 2023 – last year, the expected industry growth rate was 97%. No doubt, geopolitical instabilities have had a significant impact on these percentages.

In terms of the semiconductor opportunities, the automotive industry is seen as the most important revenue driver, for the first time. Wireless communications has dropped to the number two spot, with IoT, cloud computing and AI the next three on the list. The metaverse has yet to register significantly in terms of semiconductor revenue, but how might this change over time?!

Broadly speaking, industry executives are confident that problems with the semiconductor supply chain are on their way to being fixed. However, a major concern, in fact the major concern, for the sector is the skills shortage. A skills shortage both in terms of attracting enough specialists to join the industry and also in developing and retaining workforce talent.

The number two concerns? Geopolitics. Not so much the Russia-Ukraine war, rather the moves being made around nationalisation of semiconductor technology. It would seem that what the pandemic started, recent geopolitical instabilities have continued – the growing awareness that global supply chains, on which virtually every country relies to a greater or lesser extent, are not as robust as they were thought to be and/or need to be.

Yes, this applies very significantly to the semiconductor space, but equally to energy and food supplies. I even had a conversation the other day with someone who suggested that the lack of a European-owned cloud was a potentially major weakness for the region.

Of equal concern as geopolitics to the semiconductor executives is global inflation. Not unrelated to geopolitics, there are grounds for optimism that inflation is gradually being brought under control in many countries. However, so many national economies seem to be so fragile right now that it wouldn't take much to send them into inflationary freefall once again.

Before finishing my first editorial comment for Silicon Semiconductor magazine, I should like to pay tribute to my predecessor, Mark Andrews, who had a deservedly high reputation within the industry, and who has provided me with invaluable help since I took on the editor's role. This issue contains a couple of Q and A articles he completed before his retirement, and I am hoping that, once settled into his new home, Mark will continue his links with the magazine as and when his other commitments allow.

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Industry expects supply chain challenges to ease by 2024

Continued investment in innovation critical to semiconductor growth, including metaverse, digital health, mobility and sustainability.

THREE-QUARTERS (76%) of semiconductor executives expect the industry's supply chain challenges to ease by 2024, yet companies need to be prepared to withstand other market pressures by focusing on investments that will help drive future growth, according to a new study from Accenture (NYSE: ACN).

The report, titled "Pulse of the Semiconductor Industry: Balancing Resilience with Innovation," is based on a global survey of 300 senior semiconductor executives who evaluate their companies' supply chain outlooks and innovation roadmaps.

The executives cited challenges that could affect their ability to innovate even as the lingering effects of COVID-19 on the supply chain lift. The other challenges identified most often were geopolitics (cited by 48% of respondents), cybersecurity threats (42%), the changing competitive landscape (39%) and talent shortages (35%), among others.

Faced with a changing industry landscape, two-thirds (65%) of the executives said they believe that the rate of Moore's law — in which the number of transistors in an integrated circuit doubles about every two years — will slow down by 2024. In addition, 56% believe that promoting strong IP protection and enforcement is one of the best ways to enhance the industry's resilience moving forward.

"As the demand for chips slows down amid inflationary concerns and an easing of the chip shortage, semiconductor businesses face a new set of challenges driven by geopolitics and a growing talent shortage," said Syed Alam, global lead of Accenture's High Tech industry practice. "To succeed, companies need to balance being resilient in tough times with continued investments in innovation."

The report identifies areas for investment that will drive future semiconductor growth, including:

- **The Metaverse –** Two-thirds (67%) of executives believe that semiconductors are the most critical technology to the development of the metaverse, and 44% of executives expect to allocate more than 20% of their semiconductor production budget to the metaverse by 2024.
- **Digital Health –** Fitness trackers and smart watches represent the biggest growth opportunity for the industry, as these popular devices will benefit most from improved connectivity enabled by semiconductors.
- **Mobility –** Extended chip shortages and cost concerns are cited as the biggest roadblocks to mobility's future, leading 93% of executives to believe that car manufacturers should partner with semiconductor and technology businesses to develop next-generation mobility technologies.
- **Sustainability –** More than nine in 10 executives (93%) believe that sustainability initiatives will have a positive impact on profitability and create more sustainable consumer products. Sustainability was also cited as the area most likely to play the largest role in the semiconductor value chain within the next five years.

Faced with a changing industry landscape, two-thirds (65%) of the executives said they believe that the rate of Moore's law — in which the number of transistors in an integrated circuit doubles about every two years — will slow down by 2024

GlobalFoundries and GM reach long-term agreement

General Motors and GlobalFoundries have formed a strategic, long-term agreement establishing a dedicated capacity corridor exclusively for GM's chip supply.

THROUGH this first-of-its-kind agreement, GF will manufacture for GM's key chip suppliers at GF's advanced semiconductor facility in upstate New York bringing a critical process to the U.S.

This agreement supports GM's strategy to reduce the number of unique chips needed to power increasingly complex and tech-laden vehicles. With this strategy, chips can be produced in higher volumes and are expected to offer better quality and predictability, maximizing high value content creation for the end customer.

"We see our semiconductor requirements more than doubling over the next several years as vehicles become technology platforms," said Doug Parks, GM executive vice president of Global Product Development, Purchasing and Supply Chain. "The supply agreement with GlobalFoundries will help establish a strong, resilient supply of critical technology in the U.S. that will help GM meet this demand, while delivering new technology and features to our customers."

"At GF we are committed to working with our customers in new and innovative ways to best address the challenges of today's global supply chains," said Dr. Thomas Caulfield, president and CEO of GF. "GF will expand its production capabilities exclusively for GM's supply chain, enabling us to strengthen our partnership with the automotive industry and New York State, while further accelerating automotive innovation with U.S.-based manufacturing for a more resilient supply chain."

"This first of its kind agreement between GlobalFoundries and General Motors is going to drive the Capital Region economy forward and ensure Upstate New York remains in the driver's seat as one of the nation's leading hubs for semiconductor manufacturing that is so critical to the supply chain of the auto industry."

"I have long said that Upstate New York's semiconductor corridor will be a major engine powering America's technological future, and now 'Made in New York' chips will help jumpstart the next generation of vehicles for GM across the country," said U.S. Senate Majority Leader Charles Schumer.

"Thanks to my CHIPS and Science Act, we are bringing manufacturing back to our country and America's supply chains are being secured, creating good-paying jobs here in Upstate New York, not overseas. This partnership is yet another example that our nation's future will be built in Upstate New York, with the Capital Region as a global center for the future of the microchip industry." New York Governor Kathy Hochul said: "We're making New York State not only the semiconductor capital of the country — but of the globe. This agreement will help to further establish New York State as a major hub for semiconductor manufacturing.

"With our nation-leading Green CHIPS legislation and the new Governor's Office of Semiconductor Expansion, Management, and Integration, we are helping businesses like GM and GlobalFoundries expand the chips manufacturing ecosystem in our state, creating jobs and opportunities for generations to come."

GF is responding to the global demand for semiconductors through a series of stratgic long-term agreements with existing and new customers and simultaneously expanding global capacity to meet customer demand in partnership with federal and local governments.

Supportive policies like the bipartisan CHIPS and Science Act are encouraging the onshoring of semiconductor production and reestablishing the U.S. as a global leader of this critical technology.

Worldwide semiconductor revenue grows 1.1%

Memory market was worst performing segment, declining 10%.

WORLDWIDE semiconductor revenue increased 1.1% in 2022 to total $601.7 billion, up from $595 billion in 2021, according to preliminary results by Gartner, Inc. The combined revenue of the top 25 semiconductor vendors increased 2.8% in 2022 and accounted for 77.5% of the market.

"2022 began with many semiconductor devices in shortage resulting in extended lead times and increasing pricing which led to reduced electronic equipment production for many end markets. As a result, OEMs started hedging themselves from shortages by stockpiling chip inventory," said Andrew Norwood, VP Analyst at Gartner.

"However, by the second half of 2022, the global economy began to slow under the strain of high inflation, rising interest rates, higher energy costs and continued COVID-19 lockdowns in China, which impacted many global supply chains. Consumers also began to reduce spending, with PC and smartphone demand suffering, and then enterprises starting to reduce spending in anticipation of a global recession, all of which impacted overall semiconductor growth."

Samsung Electronics maintained the top spot although revenue declined 10.4% in 2022, primarily due to declines in memory and NAND flash sales. Intel held on to the No. 2 position with 9.7% market share. The company was impacted by the significant decline of the consumer PC market and strong competition in its core x86 processor businesses and revenue growth declined 19.5%.

Memory Revenue Declined 10% in 2022

Memory, which accounted for around 25% of semiconductor sales in 2022, was the worst-performing device category, experiencing a 10% revenue decrease. By the middle of 2022, the memory market was already showing signs of a significant collapse in demand as electronic equipment OEMs started to deplete memory inventory they had been holding in anticipation of stronger demand. Conditions have now worsened to the point where most memory companies have announced capital expenditure (capex) reductions for 2023, and some have cut wafer production to reduce inventory levels

and try to bring the markets back into balance.

Nonmemory Revenue Up 5% in 2022

Overall nonmemory revenue grew 5.3% in 2022, but the performance varied wildly across the different device categories. The strongest growth came from analog with a 19% increase, closely followed by discretes, up 15% from 2021. The growth for both analog and discretes was driven by strong demand from the automotive and industrial end markets underpinned by secular growth trends in vehicle electrification, industrial automation, and energy transition.

$50 million semiconductor partnership

THE US National Science Foundation has formed a cross-sector partnership with Ericsson, IBM, Intel, and Samsung to support the design of the next generation of semiconductors as part of its Future of Semiconductors (FuSe) initiative.

"Future semiconductors and microelectronics will require transdisciplinary research spanning materials, devices, and systems, as well as the engagement of the full spectrum of talent in the academic and industrial sectors," said NSF Director Sethuraman Panchanathan. "Partnerships such as this are essential to inform research needs, spur innovation, accelerate the translation of results to the market, and prepare the future workforce."

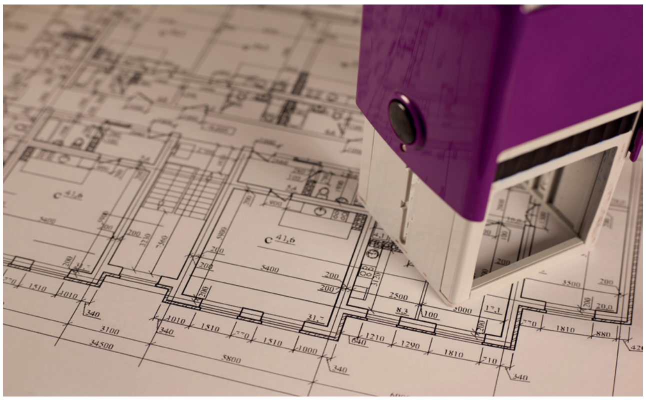
Through this partnership activity, NSF will team with Ericsson, IBM, Intel, and Samsung to invest in projects that cultivate a broad coalition of science and engineering researchers to pursue holistic, "co-design" approaches.

By intentionally supporting researchers who are integrating materials, devices, architectures, systems, and applications, new semiconductor technology is designed and developed in an integrated way. Co-design

approaches simultaneously consider the device/system performance, manufacturability, recyclability, and impact on the environment.

Infineon kicks off new Fab in Dresden

Infineon Technologies is starting construction of its new plant for analog/mixed-signal technologies and power semiconductors.



AFTER EXTENSIVE ANALYSIS, the Infineon Management Board and supervisory bodies gave the green light for the Dresden site. The German Federal Ministry for Economic Affairs and Climate Action (BMWK) has approved an early project launch, meaning that construction can already begin before completion of the inspection of legal subsidy aspects by the European Commission.

Subject to the European Commission's state aid decision and the national grant procedure, the project is to be funded in accordance with the objectives of the European Chips Act. Infineon is seeking public funding of around one billion euros. The company plans to invest a total of approximately five billion euros in the plant, which is set to begin production in 2026. This constitutes the largest single investment in the company's history.

"We're picking up the pace by expanding our production capacities in order to leverage the growth opportunities which the megatrends decarbonization and digitalization are offering us," says Infineon CEO Jochen Hanebeck. "We see structurally growing demand for semiconductors, for example for use in renewable energies, data centers and electro-mobility. By building the 300mm Smart Power Fab in Dresden we are establishing the prerequisites necessary to successfully meet the rising demand for semiconductor solutions."

Infineon's investment is an essential contribution to achieving the European Commission's declared objective of reaching a 20 percent share of global semiconductor production in the EU by 2030. Semiconductor solutions for industrial and automotive applications from the Dresden Fab will help secure value chains in key European industries even better in the future. In addition, the investment by Infineon strengthens the manufacturing basis for the semiconductors that drive decarbonization and digitalization. Analog/mixed-signal components are used in power supply systems, for example in energy-efficient charging systems, small automotive motor control units, in data centers and in applications for the Internet of Things (IoT). The interaction of power semiconductors and analog/mixed-signal components makes it possible to create particularly energy-efficient and intelligent system solutions.

Texas Instruments selects Lehi, Utah

TEXAS INSTRUMENTS INCORPORATED (TI) plans to build its next 300-millimeter semiconductor wafer fabrication plant (or fab) in Lehi, Utah. The new fab will be located next to the company's existing 300-mm semiconductor wafer fab in Lehi, LFAB. Once completed, TI's two Lehi fabs will operate as a single fab.

"This new fab is part of our long-term, 300-mm manufacturing roadmap to build the capacity our customers will need for decades to come," said Haviv Ilan, TI executive vice president and chief operating officer, and incoming president and chief executive officer. "Our decision to build a second fab in Lehi underscores our commitment to Utah and is a testament to the talented team there who will lay the groundwork for another important chapter in TI's future. With the anticipated growth of semiconductors in electronics, particularly in industrial and automotive, and the passage of the CHIPS and Science Act, there is no better time to further invest in our internal manufacturing capacity."

The fab will be designed to meet one of the Leadership in Energy and Environmental Design (LEED) building rating system's highest levels of structural efficiency and sustainability: LEED Gold. Plans include recycling water at nearly double the rate of the existing Lehi fab. Advanced 300-mm equipment and processes in Lehi will further reduce waste, water and energy consumption per chip. Construction of the new fab is expected to begin in the second half of 2023, with production as early as 2026. The cost of the new fab is comprehended in TI's previously announced capital spending plan to expand manufacturing capacity and will complement TI's existing 300-mm fabs, which include DMOS6 (Dallas), RFAB1 and RFAB2 (both in Richardson, Texas), and LFAB (Lehi, Utah). TI is also building four new 300-mm wafer fabs in Sherman, Texas.

Enthought to accelerate Tokyo Electron's digital transformation

Enthought products and services will catalyse TEL's innovation potential, expand Enthought's footprint in Japan.

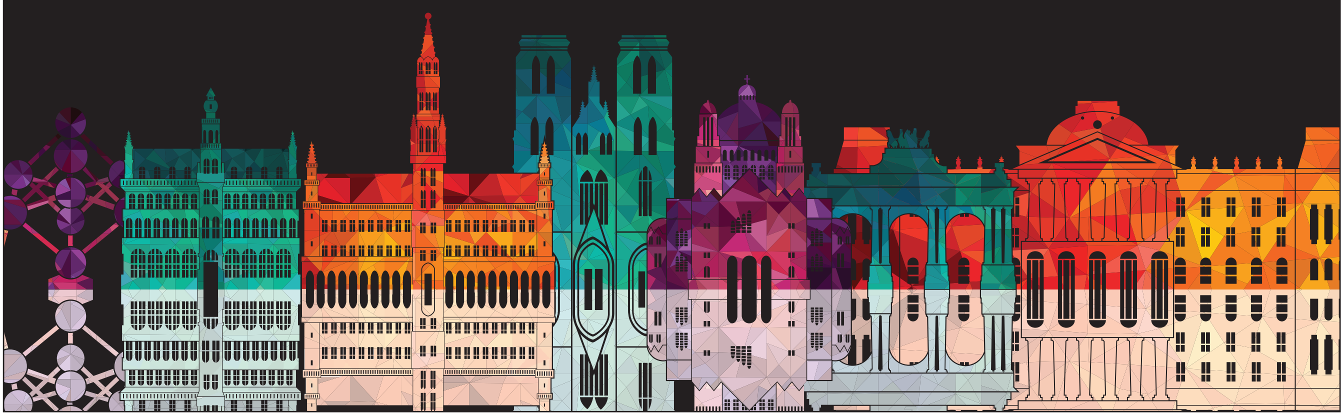
ENTHOUGHT has entered into a five-year agreement with Japanese electronics and semiconductor company, TEL, to provide services and software to accelerate their digital transformation (DX) initiatives. Additionally, TEL Venture Capital made an equity investment in the company. Since 2018, TEL has engaged Enthought to deliver its integrated solutions of software, services and the upskilling of TEL's internal teams to successfully execute its digital transformation strategy. The new agreement will extend and broaden the success of these initiatives.

"As the semiconductor industry continues to grow and evolve, having a robust digital transformation infrastructure in place is critical to accelerating the speed of chip development, improving productivity and meeting global demand," said Dr. Shinako Matsuyama, Vice President at TEL. "Over the past four years that we've partnered with Enthought, their team has played a key role in ensuring our teams have the tools and digital capabilities that drive improved operational efficiency, enable us to serve our customers better and accelerate innovation to achieve value from new opportunities, faster than ever before. We look forward to expanding our DX capabilities even further in this next chapter with Enthought."

Enthought believes that, to form a fully realizable digital transformation strategy, change must be foundational, iterative and comprehensive.

The company's approach combines technology and deep scientific expertise to enable faster discovery and continuous innovation across a variety of functions within the semiconductor industry.

"We have enjoyed a fruitful relationship with TEL over the years, and are incredibly excited for the opportunity to continue sharing our domain expertise and integrated people, process and technology approach with their team," said William Cowan, President at Enthought. "This agreement is a testament to TEL's vision of digital transformation as a key driver for sustainable competitive advantage now and into the future" added Keiichi Enjoji, President of TEL Venture Capital.



Predicting wafer process outcomes

Gauss Labs, an industrial AI startup SK hynix invested in, delivers an AI-based virtual metrology solution called "Panoptes VM" for high-volume manufacturing.

LOOKING to improve operational efficiency and yield in its semiconductor manufacturing process, SK hynix has turned to an artificial intelligence (AI) solution. Gauss Labs, an industrial AI startup SK hynix invested in, launched an AI-based virtual metrology (VM) solution software product called Panoptes VM in November 2022. Right after in December 2022, SK hynix began using Panoptes VM in its mass production fabs.

Panoptes VM predicts manufacturing process outcomes using sensor data. The product is named after Panoptes in Greek mythology, the all-seeing giant with 100 eyes. Accordingly, Panoptes VM is designed to monitor everything that happens during the manufacturing process.

Panoptes VM was first applied to thin film vapor deposition, a crucial process that coats a thin film on a wafer. The thickness and refractive index of the thin film are key process outcomes that are directly related to the quality of a semiconductor chip.

However, measuring these process outcomes for such a thin film would take a great deal of time and resources, so it is infeasible to make measurements for all wafers.

SK hynix now relies on Panoptes VM to resolve this problem. Combining prediction values generated by Panoptes VM with APC, SK hynix reduced process variability by 21.5% on average, which also led to improvement in yield. SK hynix and Gauss Labs are considering plans to expand this technology to various processes beyond thin film vapor deposition.

Analyzing the real sensor data with AI technology, prediction models by Panoptes VM achieve a high level of accuracy comparable to physical metrology equipment. Consequently, virtual metrology allows manufacturers to monitor essentially all wafers and opens up endless possibilities through predicted values.

Mike Kim, CEO of Gauss Labs, said: "Gauss Labs is solving the most challenging problems in manufacturing by using state-of-the-art AI technology and creating real impact and values in practice. With Panoptes VM at the forefront, we will continue to develop products that will lead innovation in manufacturing."

Regarding the adoption of Panoptes VM, Young-sik Kim, EVP of Manufacturing/Technology at SK hynix, said: "SK hynix is making concerted efforts with Gauss Labs to realize smart factories with a next level of intelligence."

"We will continue to maintain our technological edge by incorporating AI technology into all stages of semiconductor manufacturing. The arrival of Panoptes VM is just the beginning."

Chipletz selects Siemens' EDA solutions

AFTER an extensive technical evaluation of available solutions, Chipletz selected a suite of Siemens' industry-leading EDA tools for the design and verification of its Smart Substrate technology, which facilitates the heterogeneous integration of multiple ICs in a single package for critical artificial intelligence workloads, immersive consumer experiences, and high-performance computing.

"The Chipletz vision is to revolutionize semiconductor in-package functionality through the development of advanced packaging technology that bridges the gap between the slowing of Moore's Law and the rising demand for compute performance," said Bryan Black, chief executive officer of Chipletz.

"Our Smart Substrate designs, now in development, are very demanding. Siemens has demonstrated that they have the ideal technology for our needs."

To design and verify the heterogeneous integration of multiple ICs into a Smart Substrate based package, Chipletz selected Siemens' Xpedition™ Substrate Integrator software, Xpedition™ Package Designer software, Hyperlynx™ software and Calibre® 3DSTACK software solutions.

"Siemens is honored to be selected by Chipletz as a primary semiconductor packaging design and verification supplier," said AJ Incorvaia, senior vice president of Electronic Board Systems at Siemens Digital Industries Software.

"The Chipletz Smart Substrate technology offers Chipletz customers a robust path to bring multiple ICs, even from different vendors, into a wide range of system-in-package configurations using Siemens' design tools to deliver a high-performing and cost-effective end-product."

First EUV light marks key milestone for production of Intel 4 in Europe

Intel's first European high volume EUV scanner, located at its Fab 34 facility in Ireland, generated its 13.5 nanometre wavelength light for the first time just before Christmas.

EARLIER THIS YEAR Fab 34 in Ireland took delivery of its first EUV lithography system, a key enabler of Intel 4 process technology. The system, made by Dutch manufacturer ASML, is arguably the most complicated piece of machinery humans have ever built. Since its arrival, local teams have been working through the installation phase and recently reached an important moment as the EUV scanner generated its 13.5 nanometre wavelength light for the first time in Ireland.

This is a key milestone on the path towards high volume production of Intel 4 technology and is the first time a high volume EUV scanner will be used in Europe. Preparing for a critical milestone. The EUV system consists of 100,000 parts, 3,000 cables, 40,000 bolts and more than a mile of hosing. It took 18 months of design and construction activity to prepare the Fab 34 building to receive the machine. Following its arrival in Leixlip, the journey to generating first light has been an incredibly complex one that relied upon the intricate alignment of multiple factors. From the build of the scanner itself to the qualification of facility systems and the connection to utilities, it has taken a huge, combined team effort to reach this point.

Generating first light

In the lithography process, patterns are transferred to a silicon wafer, creating the blueprints for our integrated circuits. While lithography scanners have been an integral part of making microchips for many years, EUV scanners can print circuitry smaller and more precisely than anything that has come before.

The systems to support the EUV scanner begin at the utility, or basement, level of the fab where the vacuum pumps to create the vacuum environment and RF control cabinets for power inputs to the laser, are located. In the Subfab – which is located directly below the cleanroom - Intel has a powerful 25KW laser that generates light fired at 50,000 times per second as well as a suite of control and purification cabinets. This laser light travels up through a beam transport system to the EUV tool which is located in the main fab cleanroom.

Inside the tool, molten tin droplets are fired and struck twice by the laser. The first low power strike turns the tin droplet into a pancake shape. The second high energy strike creates the EUV plasma to form the 13.5 nanometre light which is reflected through mirrors to pick up the design template – called a reticle - and pattern it to the silicon wafer. Just before Christmas, the light was produced for the very first time in Intel's first high volume EUV scanner in Europe.

Intel 4 process technology

This milestone has been many years in the making. The planning, preparation and precision required to deliver EUV lithography in high volume production is 'unparalleled'. The arrival of this important moment ushers the way for Intel 4 technology, which has achieved its key milestone of manufacturing readiness by 2H 2022 for products such as Meteor Lake in 2023. Intel's unique process innovations and approach to EUV with the Intel 4 process keep Intel on track to deliver five nodes in four years and meet its commitment to regain process leadership by 2025.

Benefits of plasma dicing technology

Plasma dicing addresses the challenges of dicing smaller and thinner dies; enables higher throughput and increased yield per wafer.

BY SHOGO OKITA, NORIYUKI MATSUBARA, ATSUSHI HARIKAI, AND JAMES WEBER AT PANASONIC CONNECT

IT COULD BE ARGUED that the defining feature of the Electronics Industry is the ability to miniaturize. Every person with a passing interest in electronics has heard of Moore's Law: the processing power of affordable CPUs – or the number of transistors on a chip - will roughly double every two years. It is credit to both Gordon Moore's foresight, and the technical and engineering teams around the world who continue to innovate, that the 'Law' is still even being discussed today. Part of the reason for chip size reduction lies in the shrinking of technology nodes (process geometries). Currently the smallest node that is being manufactured in mass volume is 7nm, and even the smaller size is under development in the industry.

APX300 Plasma Dicer

The increase in processing power and speed and the miniaturisation and integration of electronic functions that continue to result from such technological advances lie at the heart of the pervasiveness of electronics in our everyday lives: the smart phones that we rely on; the uptake of artificial intelligence in smart homes and cities; driverless vehicles; remote medical home diagnostics – there is not one aspect of life that electronic products and systems have not penetrated.

But for this to continue, it is not only in the area of photolithographic processing that technology needs to keep innovating. Once a wafer has been created it must be singulated into individual dies, and as dies are becoming smaller and thinner, many products are facing difficulties caused by the singulation or dicing process. New challenges include: increasing material loss due to the width of the dicing street; mechanical damage such as chipping; and increasing processing time. Now, Panasonic has developed a plasma dicing process that in certain circumstances can replace mechanical dicing, which addresses these issues.

Types of Dicing Process

Traditionally, two dicing technologies have been used: scribing and breaking, and mechanical cutting using a dicing saw ("blade dicing"). Scribing and breaking causes stresses on the wafer and die and results in chipping and yield inefficiencies. Blade dicing also introduces stresses and contaminants which are more problematic as the die size and process geometries shrink. Laser dicing is another method which is faster than using a saw, but can also cause cracking and damage to the chip.

Now, a new dicing process has been introduced which uses a plasma chemical etching process, where all the 'cuts' are achieved in a single batch process, with no die stressing, no contamination, and an increase in wafer dicing throughput. Also, more chips can be designed onto the wafer as narrower dicing 'streets' can be used due to mask patterning. In addition, the mask pattern enables flexibility in the choice of chip sizes, shapes, positioning. The two approaches are shown in Figure 1.

Figure 2 shows Panasonic's plasma dicing process which uses a dicing mask. The plasma process etches the streets by chemical reaction. Plasma dicing uses pulsed or time-multiplexed etching, with the process cycling repeatedly between two phases: a near-isotropic plasma etch where ions attack the wafer in a near-vertical direction; followed by the deposition of a chemically inert passivation layer which protects the entire substrate from further chemical attack. During etching, the vertically-directed ions attack the passivation layer only at the bottom of the trench (not along the walls), exposing the substrate to the chemical etch. This two-phase process results in side-walls that increase and decrease with an amplitude of between 100 and 500nm. The cycle time is adjustable: short cycles yield smooth walls; longer cycles yield a higher etch rate.

Advantages of the plasma process over mechanical dicing

The action of the saw blade during the dicing process causes mechanical damage and affects inner layers of the die. Figure 3 demonstrates damage and chipping at the edge and of the inner layers. By contrast, the micro-photographs show no damage when the individual dies are separated using the plasma dicing process. Also, unlike blade dicing which causes micro particles of the wafer (e.g. silicon) to be freed up, potentially causing devices to fail, by using plasma etching, no contaminating particles are released.

Greater chip strength

Chip breakage tests show the typical range of fracture strength for silicon chips to be in the range of 100MPa up to 3000MPa. Dies from several positions on a 150µm thick wafer were sampled and a Weibull plot was used to compare the statistical data for chip strengths of lots using blade and plasma dicing preparation methods. Figure 4 shows that the plasma dicing process results in chips that are about five times stronger than those which

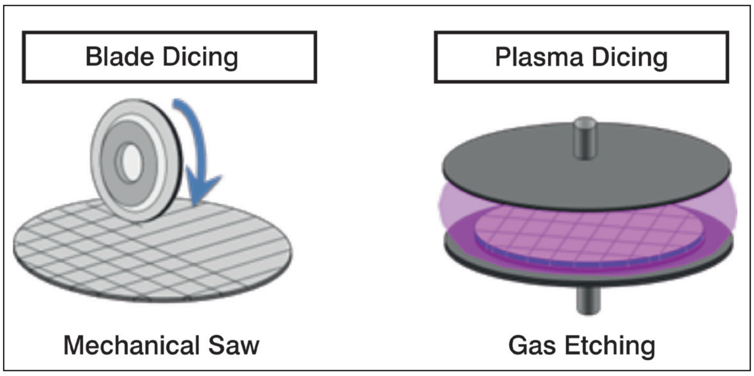


Figure 1. Blade Dicing & Plasma Dicing Processing

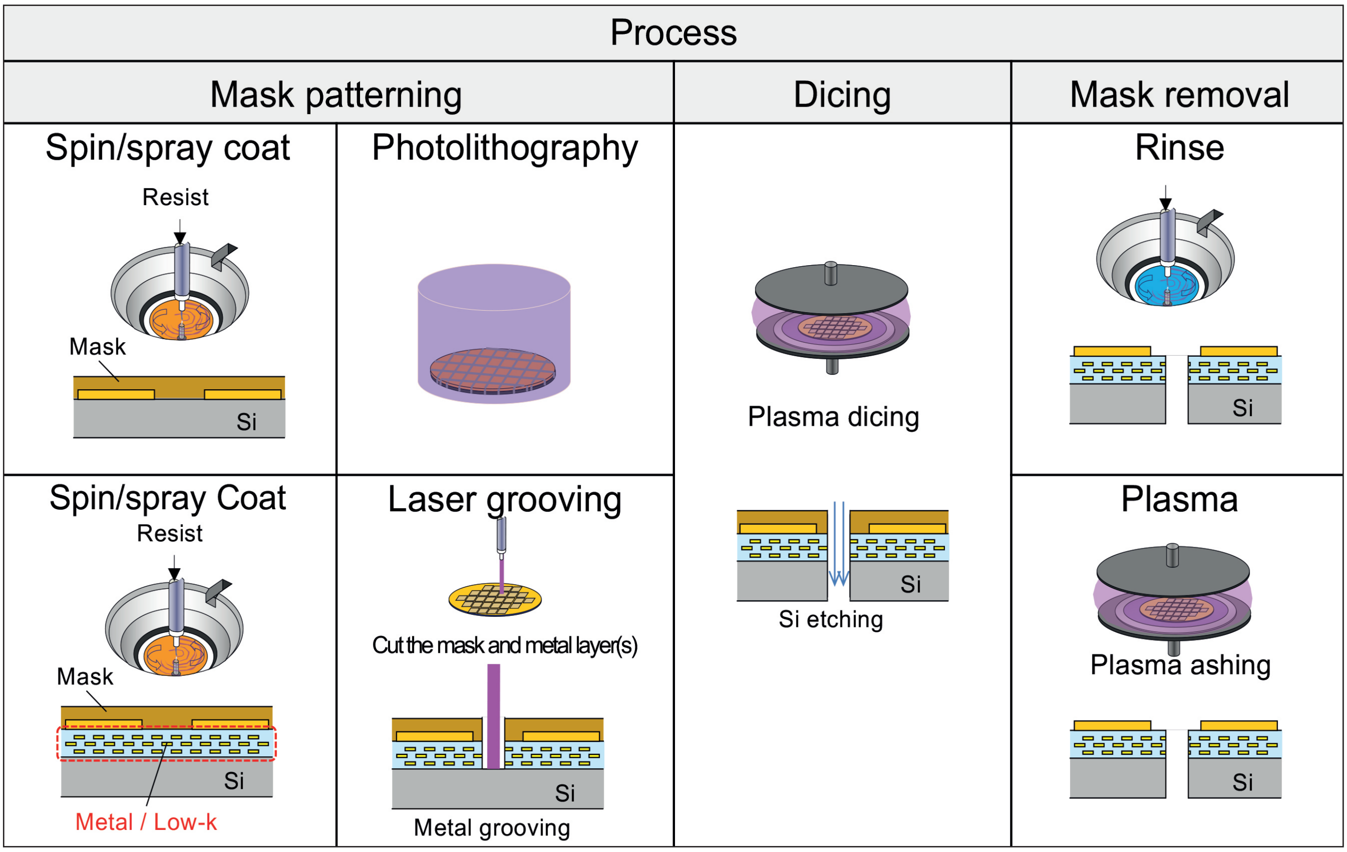
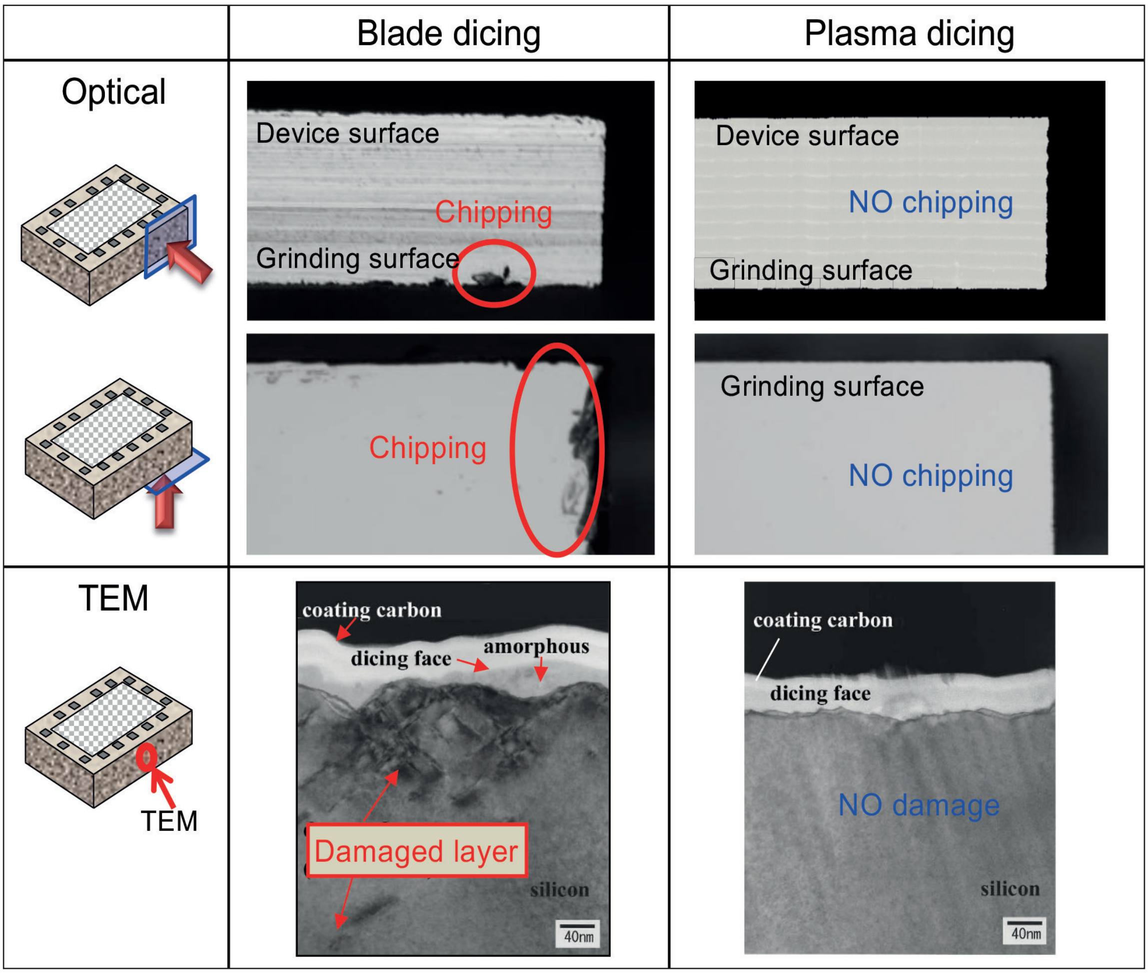


Figure 2. Panasonic's chemical etch dicing process



➤ Figure 3. Damage evident on chip samples using blade dicing (left); none present when plasma dicing is used

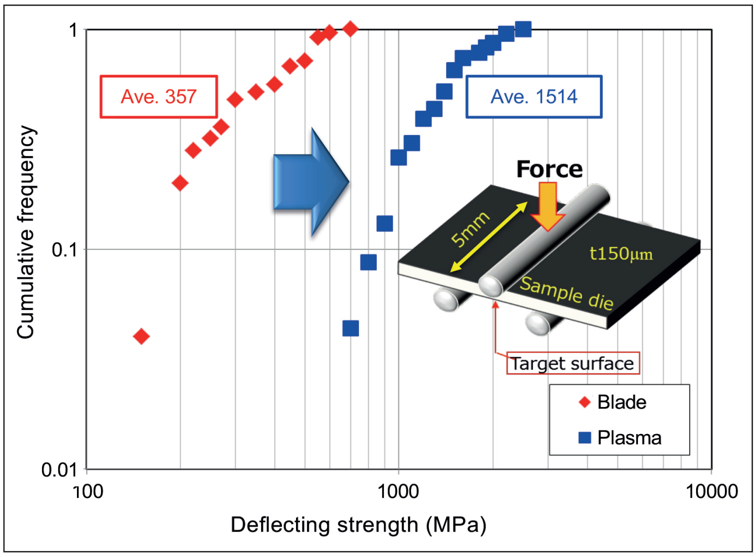
underwent blade dicing. With a fracture stress pressure of 600MPa, all samples of chips that had been processed using blade dicing broke due to internal micro-cracks, whereas all of the plasma diced chips shattered at a pressure close to the breaking-strength of silicon.

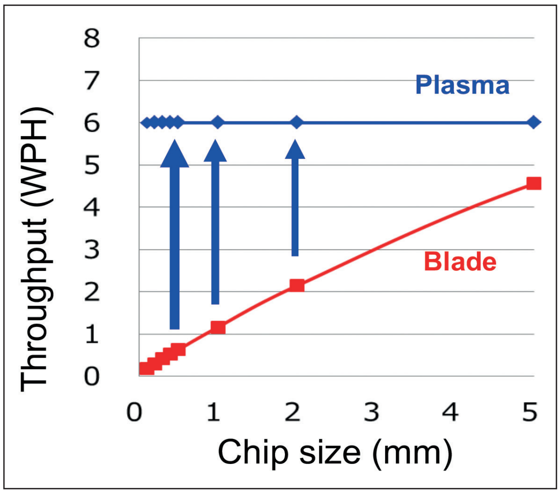
Therefore the plasma dicing process is proven to result in dramatically higher chip strength, especially if thin wafers are being processed.

➤ Figure 4. Strength tests prove the benefits of plasma dicing

Higher throughput and yield

The processing time of blade dicing depends on the number of dicing lines. If the die size is small, longer dicing processing time is required and throughput is reduced. However, with the plasma dicing process, etching is performed across the whole wafer in one pass, so throughput remains constant, no matter how many dicing streets are required (see Figure 5). In addition, the plasma dicing process uses a narrower dicing street design. With blade dicing,





➤ Figure 5. Productivity curves show increasing benefits with smaller chip areas

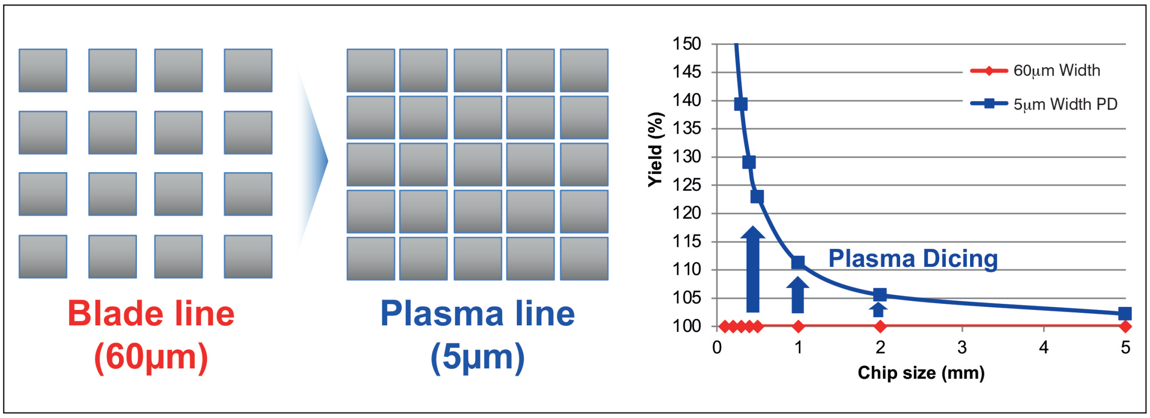


Figure 6. reduced street widths result in more chips/ wafer

there is always a minimum cutting street width, due to the thickness of the blade. A simulation prepared by Panasonic shows that for a 0.5mm^2 chip size, reducing the dicing street width from 60µm to 5 µm, yield will be increased by 23% using the new plasma process. (See Figure 6). But how to avoid chips to contact others when handling wafer with 5 um dicing street width needs to be considered.

Suitability for different wafer processes

The Panasonic plasma dicing process can be applied to wafer dicing with mask patterning either performed by photolithography or laser patterning methods. The appropriate process flow should be selected to fit the wafer design (Figure 7).

Plasma dicing is a high quality innovation which offers different benefits depending on the end application, as shown in Figure 8. In small chips, for example, RF ID tags, IoT devices or MEMS sensors, the ability to obtain a higher number of chips per wafer, plus the reduction in process time is paramount. For devices such as image sensors, the elimination of contaminating particles is essential, and the smoother, damage-free sidewalls, with no heat-affected zones or cracking, allows an increase in the active area. For makers of memory ICs, the elimination of damage is most significant.

Panasonic Demo Centre

In order to demonstrate the plasma dicing process, Panasonic has built a customer demonstration centre in Osaka, Japan. This Class 1000 facility is capable of processing 200mm and 300mm diameter wafers with a minimum thickness of 25µm. It is fully-equipped including two APX300 plasma dicing machines, laser patterning equipment, polish grinder, lithography and measurement equipment, enabling customers to quickly and thoroughly evaluate different products and materials.

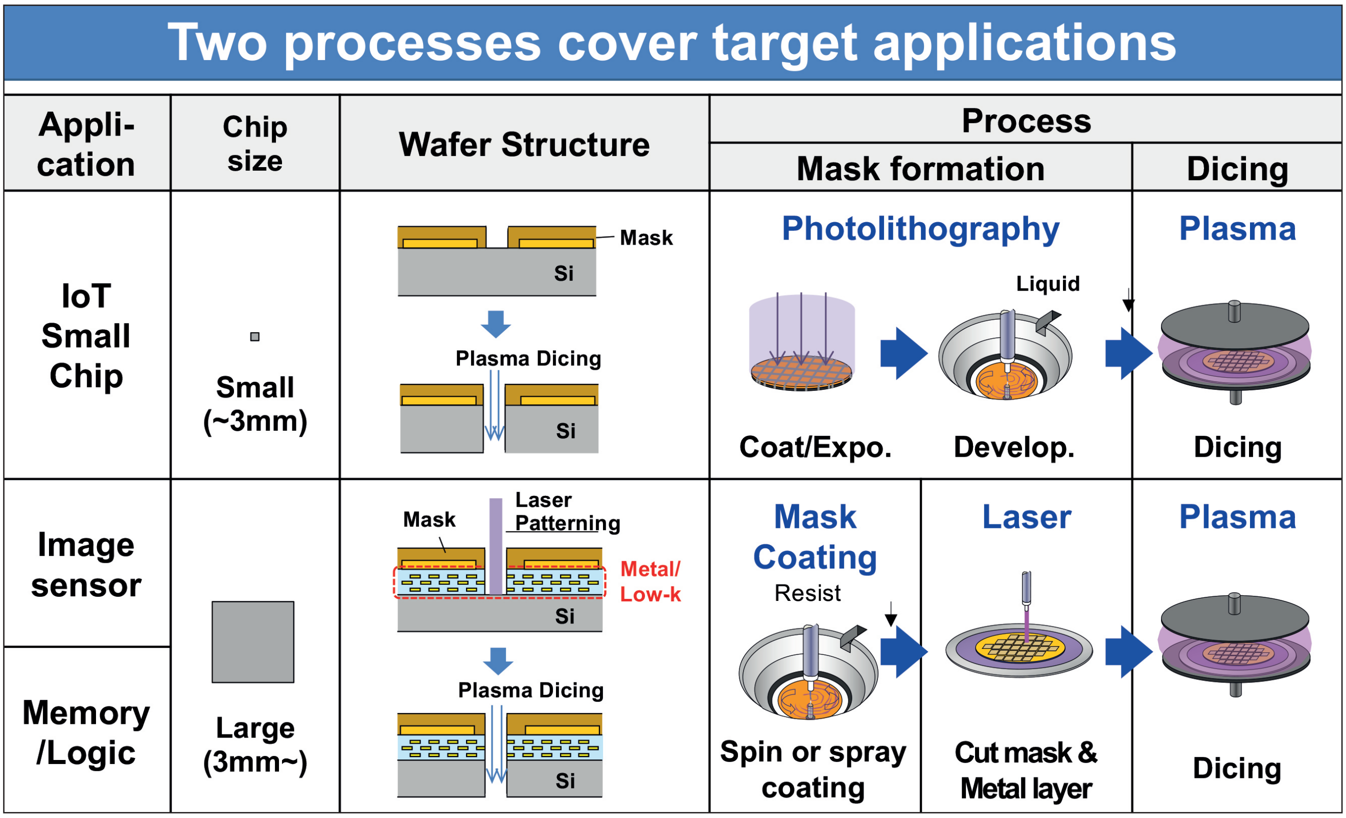


Figure 7. Panasonic plasma dicing process Applications

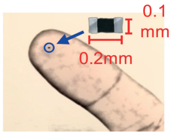
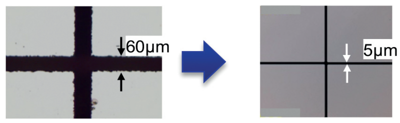
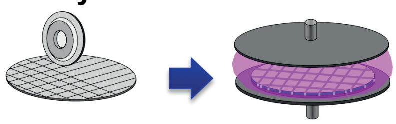
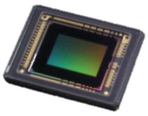
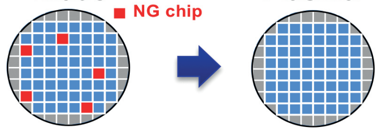
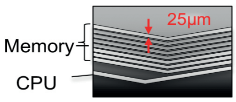
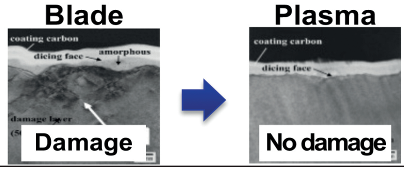
Target Application	Blade Dicing Issues	Benefits of using Plasma Dicing	
 IoT Small chip ·RF-ID tag ·Chip component ·MEMS etc..	Wider dicing lane (W 60µm)	Narrower lane (W 5µm) → More chips from a wafer	Blade → Plasma 
	Longer process time in smaller dies	Shorter process time →lower COO	Line-by-line → Whole wafer 
 Image Sensor	Particle from blading, less yield	Particle free →improve yield	Blade → Plasma 
 Memory	Chipping/die breakage due to damage	Damage free chip obtained →new value for end user	Blade → Plasma 

Figure 8. Benefits of Plasma Dicing

Conclusion

Panasonic's plasma dicing process achieves damage-free and particle-free dicing, resulting in inherently stronger chips and increased yield. Throughput is increased and production costs reduced. Figure 9 summarises the different dicing processes and the advantages of the plasma dicing process.

All the data in this white paper have been verified in Panasonic's Plasma Dicing Demo Centre in the company's Smart Factory Solutions facility in Osaka, Japan, using the APX300 plasma dicer. Panasonic are continuing to develop the plasma dicing process for other materials such as silicon carbide, gallium arsenide and gallium nitride as well as silicon dioxide.

Product Information

Panasonic can provide a plasma dicing total solution to achieve a damage-free, particle free, higher throughput and lower overall cost of production.

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85521 Ottobrunn, Germany

Tel. +49 89 45354-1000

microelectronics.sales@eu.panasonic.com
http://pfse.panasonic.eu

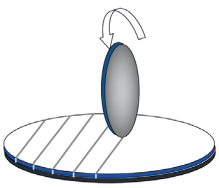
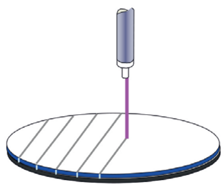
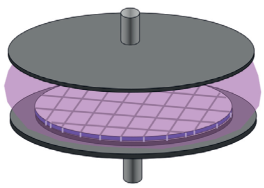
	Blade	Laser	Plasma
Dicing method			
Processing time (8"wafer, t 100µm, □1mm)	✗ (32 min / wafer)	✓ (13 min / wafer)	✓ Shortest (7 min / wafer)
Chip strength	✗ (Mechanical damage)	✓ (Mechanical damage)	✓ Highest (Damage-free)
Low-k etching	✗ (Wet process)	✓ (Dry process)	✓ (Dry process)

Figure 9. Summary comparison of dicing processes

Automotive semiconductors:
Changing the face of vehicular electronics

The market for automotive semiconductors is expected to grow at a rate of over 9% annually through 2030. Automobile semiconductor content will increase significantly as electric vehicles and ADAS become more prevalent, while production volumes remain steady.

BY MOHIT SHRIVASTAVA, CHIEF ANALYST AT FUTURE MARKET INSIGHTS

THE AUTOMOTIVE INDUSTRY is undergoing a radical change at the moment that will have profound implications on how cars will be built, used, and maintained in the future. In spite of the fact that the semiconductor industry is a key enabler of this change, the impact will be felt by both manufacturers and consumers. Semiconductors for automotive applications are at the forefront of automotive technology. Powering and controlling almost every system in a modern car, from driver assistance to infotainment, they play a crucial role in the overall operation of that vehicle. Rapid growth has been occurring in the semiconductor industry, and new technologies are constantly being developed to meet the increasing needs of automobile makers in the industry.

Providing modern vehicles with safety, performance, efficiency, and safety are the essential purposes of automotive semiconductors. Various auto systems rely on them, including infotainment and navigation systems, safety systems, and autonomous driving technologies in order to function properly. New technologies are continuously being introduced to the semiconductor industry, enabling advanced automotive semiconductors to provide higher performance and efficiency.

With automakers striving to improve vehicle performance and efficiency, advanced automotive semiconductors have become increasingly important. As automotive semiconductor manufacturers strive to improve the safety and efficiency of their products, artificial intelligence (AI), machine learning (ML), and computer vision technologies are becoming increasingly popular. These technologies can also be utilized to provide drivers with a more personalized experience, such as providing real-time traffic information or providing predictive maintenance services.

It is anticipated that over the next ten years, the automotive semiconductor industry will grow at a rapid pace. Automotive semiconductor revenues are expected to grow by 5.6% over the next five years. North American auto production increased by 6% over the same period, requiring more personalized experiences and more efficient systems.

Manufacturers of automotive semiconductors are committed to advancing their research and development efforts in order to improve the low-power efficiency of advanced automotive semiconductors, increasing their commitment to innovation. With the advent of AI and machine learning, the industry has developed technological advancements that help with autonomous driving, like lane departure warnings and automatic braking. Technological Development Supports

Semiconductor Industry Growth

A semiconductor device for automotive applications is constantly evolving and developing rapidly. Automotive semiconductors play a significant role in powering engines, controlling systems, and providing safety features in modern vehicles. Emissions and fuel efficiency have also been improved by automotive semiconductor technology. New technologies are constantly being developed for cars and other vehicles by the automotive semiconductor industry. Enhanced sensors, microcontrollers, processors, memory, and power management systems improve performance and safety. Continuing to grow and develop new technologies, the automotive industry will demand advanced automotive semiconductors.

Over the past several years, the semiconductor industry has made significant investments in the development of technologies that are used by automotive semiconductors. In order to power modern cars, advanced sensors, processors, memory chips, and a variety of other components are used. These technologies are widely used in advanced cars today. Furthermore, they are also helpful in reducing the number of emissions produced by vehicles and improving fuel efficiency.

Apart from these technologies, automotive semiconductors have also been used as a component of autonomous driving systems, connected vehicle services, and vehicle-to-vehicle communication systems, among other applications. The future of driving will be enhanced with smarter and safer cars as this technology continues to evolve. With the advancements in semiconductor technology for automotive manufacturing,

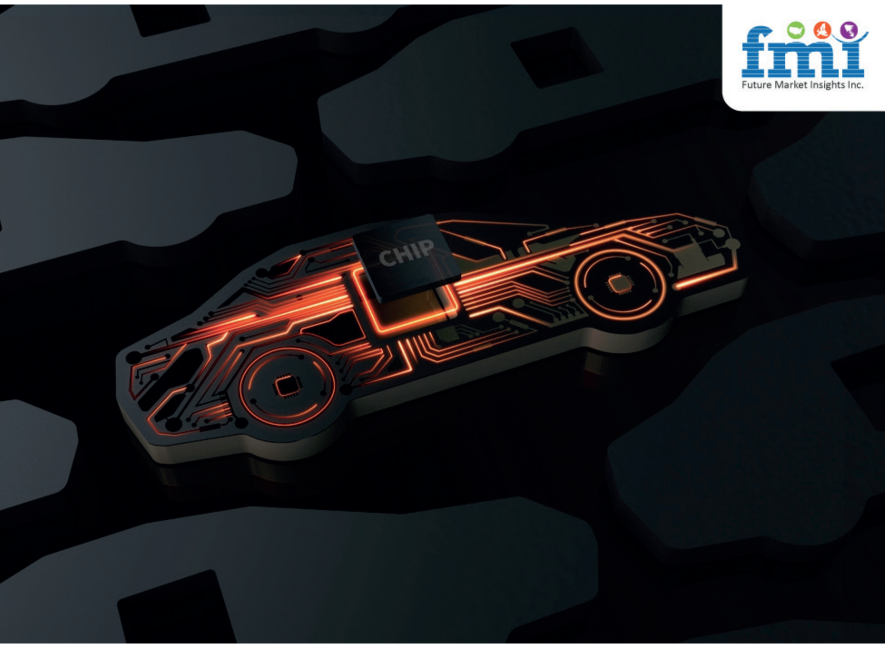
automakers are now able to create vehicles that are more powerful and have enhanced connectivity capabilities for the customer. Vehicle performance is improved by automotive semiconductors through technologies such as 5G networks, machine learning, and artificial intelligence. Automotive semiconductors use a variety of technologies, which can be applied in a variety of applications.

A Look at the Future of Semiconductor Shortages in Automobiles

Some form of semiconductor shortages may persist in the automotive industry until 2026. There has been a cyclical decline in chip demand due to pandemic-induced manufacturing and logistics challenges. As oil prices rose in recent months, China experienced a resurgence of Covid cases, and exports declined 5.7% compared to the previous year, increasing the likelihood of a supply-side crunch. With ADAS and electrification becoming more advanced, further growth in automotive semiconductor demand is inevitable as these technologies progress in the coming years.

Since vehicles are becoming increasingly sophisticated, the imbalance between supply and demand will continue, even with recent capacity expansions, at least in regard to certain semiconductor components. Although the nature of these chip shortages is likely to change over time, automakers will be required to actively manage risks when it comes to chip shortages, since the type of devices affected will also change over time. Changing circumstances will require automakers to actively manage risks in the future.

According to BCG, the market for automotive semiconductors is expected to grow at a rate of over 9% annually through 2030. Automobile semiconductor content will increase significantly as electric vehicles and ADAS become more prevalent, while production volumes remain steady.



Government's Contribution to Automotive Semiconductor Industry

Research projects related to automotive semiconductors are being funded heavily by governments around the world, contributing to regional growth. There are several government-sponsored projects being conducted in the automotive industry in order to improve safety, fuel efficiency, and emissions standards. Several emerging markets such as China, India, and Brazil are experiencing significant regional growth due to the need for more efficient cars in these markets. To make India a global hub for electronics manufacturing, with semiconductors as a cornerstone, incentives were announced in December worth Rs 2.3 lakh crore ($30.7 billion).

As an integral component of the automotive industry, automotive semiconductors enable various automotive features, including safety, entertainment, and navigation. For instance, Bangalore's Tech Park now has an R&D center for the creation of specialized automotive, internet of things, and consumer electronics systems from NXP, a major semiconductor designer in Europe, such as radars and NFC technology, as well as energy-saving chips for cars. The laboratory will be able to help increase the long-term capacity of India's microelectronics industry by leveraging its expertise. As a result of India's automotive market boom, it has become increasingly important for the country to develop its own microelectronics industry in order to achieve its strategic goals.

Could India be the next Colossal Investment Market? Among the industries in which India excels are semiconductor design and semiconductor software. However, most talented engineers in India are employed by leading global companies' captive design centers, which limits their exposure to top talent. Despite being a country that designs electronic chips and employs nearly 20,000 engineers, India does not yet have semiconductor manufacturers. The Indian import share is also expected to quadruple in the next few years. According to the Indian government, the country imports 25 times more electronic components than oil. With the advent of the 6G, the demand for this technology will skyrocket in the future.

According to the India Electronics and Semiconductor Association, the Indian government intends to double the market for semiconductors by 2026 to $64 billion as part of the new organization plan. India has been providing subsidies of up to 50 percent for the construction of screen and semiconductor factories in order to compete with leading players like Taiwan and South Korea, which often require multi-billion dollar investments in order to build these factories.

Conclusion

The automotive semiconductor industry is expected to experience robust growth in the foreseeable future due to a wide range of factors, such as increasing demand for advanced driver assistance systems, growing electrification of vehicles, and advancements in autonomous technologies. With this projected growth, semiconductor demand will likely increase as well as new opportunities within this industry will emerge. A wide range of advanced driver assistance systems (ADAS), electric and autonomous vehicles are being developed. As automotive systems become increasingly intelligent and powerful, automotive semiconductors will become indispensable components. The automotive industry will be increasingly dependent on semiconductors in the near future.

As autonomous vehicles become more advanced, semiconductor technologies will become increasingly important. As these systems become more complex, they will require more powerful processors, sensors, and other semiconductors. Moreover, the automotive industry will be greatly impacted by the development of the fifth generation of mobile networks. The use of 5G networks for communicating and transferring data between cars will become more and more common in the future. In order to ensure reliable and secure data transmission, components, and semiconductors with high performance will be required.

As autonomous vehicles become more advanced, semiconductor technologies will become increasingly important. As these systems become more complex, they will require more powerful processors, sensors, and other semiconductors

New semiconductor technologies will be driven by the demand for comfort, safety, and convenience features. With advances in artificial intelligence and voice recognition, automakers can provide drivers with a more customized experience. By developing new semiconductor technologies, engineers will be able to produce more powerful and efficient processors and sensors. Moreover, the development of new semiconductor technologies will also be influenced by the rise of electric vehicles. Developing new semiconductor technologies will enable the development of batteries and power management systems that will be more efficient, powerful, and safe for autonomous vehicles.

A view of the electronics supply chain in 2023

Companies with access to commodity-level intelligence can respond to changing market conditions, more thoughtfully select which components and materials to design into their products, and align sourcing teams to ensure supply is available when and where it is needed.

BY JOHN WARD, SENIOR DIRECTOR, DSI SOLUTIONS – COMMODITY IQ, SUPPLYFRAME

THE GLOBAL ELECTRONICS supply chain has taken a few hits over recent years. Once the invisible machine working around the clock across the globe to deliver, well, everything, the COVID-19 pandemic ushered in a new age – one where mixed end-market signals, macroeconomic uncertainty, and difficulty forecasting demand, paired with the pandemic, have evolved from a black swan event into a black swarm of events.

State of the market in Q1 2023

Recession risks have subsided somewhat, and central banks are advancing in controlling inflation. Still, electronic component lead times are improving faster than prices as demand deteriorates in some markets, inventories are at historical highs, and new disruptions could emerge with a further intensification of the Russia-Ukraine war and China's continuous COVID-19 challenges.

In early May 2022, Supplyframe's predictive intelligence identified the sharp downturn in consumer electronics, PC, and smartphone demand by analysing the engineering design actions, demand sourcing signals, and contract pricing for specific electronics components widely employed in these sectors like DDR4 DRAM in PCs. This is the downturn we are still experiencing, in addition to weakened hyperscaler and enterprise server demand.

The Supplyframe Commodity IQ solution – which provides always-on, holistic electronics supply chain analytics and analysis – has revealed that the electronic components value chain is getting some pricing and lead time relief for the first time in several quarters. However, price reductions are still hard to achieve despite lower demand and lead times. While inventories may have peaked in some categories in Q4 2022, electronic component lead times remain more prolonged than historical norms, and specific semiconductor devices still have factory lead times of over 48 weeks.

Nevertheless, there is reason to be optimistic. Commodity IQ operational metrics reveal that component availability has largely improved, and prices have stabilised across many commodities and sub-commodities, particularly for passive components. Additionally, Commodity IQ data exposes opportunities for enhanced supplier negotiations, better-timed sourcing events, and 360-degree supply chain visibility.
Commodity IQ forecasts for the first quarter of 2023 point to an 8% decline in the number of rising lead times and commodities with part allocations for active and passive components. Similarly, according to the Commodity IQ Price Index for Q1, the number of component pricing dimensions will be reduced by

14%. Moreover and unsurprisingly, global electronic component demand and sourcing activities quarter-on-quarter in Q1 will be down by 2%, while engineering design will be off by 20% – further evidence of demand erosion.

Component inventories, while bloated for some components like memory and small case-size ceramic capacitors, for devices like automotive-grade microcontrollers and FPGAs remain far below the Commodity IQ Inventory Index baseline. For example, microcontrollers and microprocessor distribution and supplier inventories in December 2022 were nearly 50% lower than in December 2021. Analog ICs, microcontrollers, and discrete ICs (especially power MOSFETs) will remain constrained and high-priced in Q1 and beyond.

What does the future hold?

With global macroeconomic and political uncertainty in the foreground, we have entered the new year with positive signs for normalising supply-demand balance and reduced pricing and availability pressure. For H2 2023, excluding memory devices, the forecast is for 85% of semiconductor pricing dimensions to be stable and the remainder to move squarely in the buyer's favour.

Extended lead times will endure into the year's second half for semiconductors, including programmable logic devices and passive components like automotive-specific resistors. Yet, as world economies exhibit remarkable resiliency in the face of inflation and threats of recessions, Q3 2023 lead times for all electronic components are forecast to ebb dramatically from Q3 2022. Nearly 60% of lead time dimensions are projected to decrease in Q3 versus about 1% in Q3 2022, and none are expected to increase in Q3 compared to a massive 73% in the same quarter of 2022.

Assuming a short and shallow recession (JPMorgan Chase is now considering a mild U.S. recession to be their baseline estimate), China truly reopens, inventory normalisation, and a return to more broad-based demand growth for semiconductors and passive devices, the electronics supply chain could very well swing back into imbalance for some part types. The resurgence in EV demand and acceleration of the trend toward commercial vehicle (Class 7 and 8 vehicles in the U.S.) electrification could tip the scales toward increased supply constraints, especially for multilayer ceramic capacitors. The real question is, despite inventory reductions that will likely be complete by the end of H1, will IC orders, wafer starts, and capacity utilisation begin to rise in the second half? Or, as a leading indicator for the semiconductor market, will memory pricing reach its bottom in the second half? Supplyframe believes so on both counts, forecasting that DRAM prices will commence recovery in the third quarter and NAND pricing will follow in Q4 or early 2024. With ongoing geopolitical tensions and advanced semiconductor-related sanctions between China and the U.S. and seemingly the rest of the world – consumers and manufacturers in the electronics space need to understand the demand pattern shifts to more mature semiconductor process nodes (≥ 40-nanometer) could be a boon for Chinese players and industries that do not have restrictions on the Chinese content of manufactured items.

Also, the industry recognises that China and Asia generally have trade lanes, raw materials access, some leading-edge frontend (≥ 14-nanometer) production, massive and advanced backend services, lower-cost technical labour, and efficient processes that will be difficult to match in net-new locations. Deciding on the appropriate combinations of friendshoring, nearshoring, onshoring, reshoring, and offshoring will be equally important to chipmakers (regardless of production models) and chip buyers.

Preparing for the future

Cautious optimism is the watch phrase for original equipment and component manufacturers, EMS providers, and distribution supply chain leaders this year. Buy-side participants in the electronics value chain must lay the foundation for resilience by treating commodity/category management as equally crucial to transactional sourcing, ensuring short-term wins are not at the expense of long-term needs, and reducing cognitive overload by viewing partners and ecosystems as strategic imperatives. They should collaborate with manufacturing partners and solution providers with the deep domain experience to receive holistic and real-world views of their supply chains.

Ultimately, companies with access to commodity-level intelligence can respond to changing market conditions, more thoughtfully select which components and materials to design into their products, and align sourcing teams to ensure supply is available when and where it is needed. This will better position them for fluctuating demand, lower their costs, and reduce their risk of product delays while affording advanced protection from the next inevitable black swarm.

Resilience is critical for supply chain success

EXIGER'S SKYLER CHI TALKS to Silicon Semiconductor reflecting on what the semiconductor industry supply chain will look like in the 'new normal' and the impact this will have on businesses and why they must diversify their supply chain to prevent disruption.

SS: *What does the semiconductor industry supply chain look like in the 'new normal', in a world where energy prices and geopolitics are causing ongoing, major disruption?*

SC: The semiconductor industry supply chain in 2023 and beyond will likely face ongoing challenges due to the effects of global regulatory changes and investment decisions. The CHIPS Act and other similar initiatives aim to boost domestic semiconductor production, leading to a fragmented and less globalised supply chain.

Additionally, the increasing focus on renewable energy sources and reducing carbon footprint will likely drive investment in new technologies such as edge computing and 5G, further complicating the supply chain. The ongoing geopolitical tensions may also lead to stricter regulations and trade restrictions, causing supply chain disruptions and hindering the flow of goods and resources.

In this new normal, companies in the semiconductor industry will need to adapt to the changing landscape through greater supply chain resilience, diversification, and investment in innovation. Additionally, the US-China trade tensions and the efforts by the US to reduce its dependence on Chinese suppliers will result in a shift in the industry's supply chain dynamics.

Companies will need to look for alternative sources and suppliers, leading to a more fragmented and localised supply chain. This could result in higher costs, longer lead times, and increased risks for companies.

Additionally, the US government's efforts to encourage domestic semiconductor production through initiatives like the CHIPS Act may lead to increased competition and reduced reliance on foreign suppliers. This could result in a more stable and secure supply chain but may also lead to higher costs and reduced innovation as companies adapt to the new landscape.

Overall, the US effort to remove China from its most critical supply chains will likely lead to significant changes in the semiconductor industry supply chain, including increased localisation, greater competition, and the need for companies to adopt new strategies to manage risks and ensure stability.

SS: *How are new regulations affecting the semiconductor industry supply chain?*

SC: New regulations are having a significant impact on the semiconductor industry supply chain. Increasingly, governments around the world are implementing regulations aimed at boosting domestic production, reducing dependence on foreign suppliers, and promoting technology security. These regulations are affecting the industry in several ways:

Domestic production (reshoring): Government initiatives like the US CHIPS Act are aimed at boosting domestic semiconductor production, which could lead to a more localised and fragmented supply chain. Companies may need to adapt to the changing landscape by investing in new technologies and expanding their local production capabilities.

Trade restrictions: Governments are also implementing trade restrictions and sanctions on certain countries and companies, which could impact the flow of goods and resources in the supply chain. Companies may need to find alternative sources of materials and components, which could increase costs and lead times. New regulations such as those designed to protect against slave labour and human rights abuses in the production of materials, including silicon, is a growing concern in the semiconductor industry. Companies are under increased pressure from consumers, governments, and advocacy groups to ensure that their supply chains are free of forced labour and human rights abuses.

Technology security: Governments are also implementing regulations aimed at protecting national security and technology, which could impact the flow of information and intellectual property in the supply chain. Companies may need to implement stronger security measures and adopt new technologies to protect their information and IP.

Environmental regulations: Governments are also implementing regulations aimed at reducing carbon emissions and promoting sustainability, which could impact the production and transportation of materials and components in the supply chain. Companies may need to invest in new technologies and adopt more sustainable practices to comply with these regulations.

Overall, new regulations are affecting the semiconductor industry supply chain by creating new challenges and uncertainties, as well as opportunities for innovation and growth. Companies will need to adapt to these changing conditions through greater supply chain resilience, diversification, and investment in technology. In high-risk regions, companies will need to implement due diligence and responsible sourcing practices to identify and eliminate slavery and human rights abuses in their supply chains. This may include conducting risk assessments, implementing supplier codes of conduct, and partnering with advocacy organisations to monitor and improve working conditions.

Failure to address these issues could result in reputational damage, decreased consumer trust, and potential legal and regulatory action. Companies will need to take proactive steps to ensure that their supply chains are free of slavery and human rights abuses, and to promote transparency and accountability in their sourcing practices.

The semiconductor industry, being a critical component of many high-tech and industrial sectors, has a responsibility to ensure that its supply chain is free of slavery and human rights abuses.

Addressing this issue will require collaboration between companies, governments, and advocacy groups, as well as a commitment to responsible and sustainable sourcing practices.

SS: *How can technology enable businesses to build stronger and more resilient semiconductor supply chains?*

SC: We at Exiger believe that technology can play a central and absolutely crucial role in enabling businesses to build stronger and more resilient semiconductor supply chains. For example, technology can assist with:

Supply chain visibility (bridging): Technology can provide real-time visibility into the flow of goods and information throughout the supply chain, enabling businesses to identify and respond to risks and disruptions more quickly.

Automated risk assessments: Technology can automatically identify and analyse risks in the supply chain, such as potential disruptions, human rights abuses, and environmental impacts, allowing businesses to make informed decisions and respond proactively.

Supplier management (buffering): Technology can help businesses manage and monitor their supplier relationships, including sub-tier suppliers, by providing a centralised platform for communication,

collaboration, and data sharing. This can help businesses reduce the risks associated with working with suppliers and ensure that suppliers are meeting their obligations.

Predictive analytics (e.g., digital twin): Technology can provide predictive analytics capabilities that help businesses anticipate and respond to potential supply chain disruptions and other risks. For example, predictive analytics can be used to analyse data on production capacity, supplier performance, and market trends to identify potential risks and make proactive decisions to mitigate them.

Blockchain technology: Blockchain technology can provide a secure and transparent ledger of all supply chain transactions, enabling businesses to ensure the integrity and accuracy of data and track the flow of goods and information throughout the supply chain.
Overall, technology can help businesses build stronger and more resilient semiconductor supply chains by providing real-time visibility, automating risk assessments, improving supplier management, enabling predictive analytics, and promoting transparency and security.

SS: *In this 'new normal' how should semiconductor industry organizations structure their supply chains to make them more resilient?*

SC: To make their supply chains more resilient in the new normal, semiconductor industry organisations should consider the following steps:
Diversify suppliers: Diversifying suppliers can reduce the risk of dependence on a single source and help to ensure that critical components and materials are available even in the event of a disruption.

Implement real-time visibility: Implementing real-time visibility technologies, such as RFID and IoT sensors, but also full network illumination and detection, can help organisations to track the flow of goods and information throughout the supply chain and respond quickly to disruptions.

Establish risk management processes: Organisations should establish robust risk management processes that enable them to identify, assess, and respond to potential supply chain risks, including those related to geopolitical tensions, natural disasters, and health pandemics.

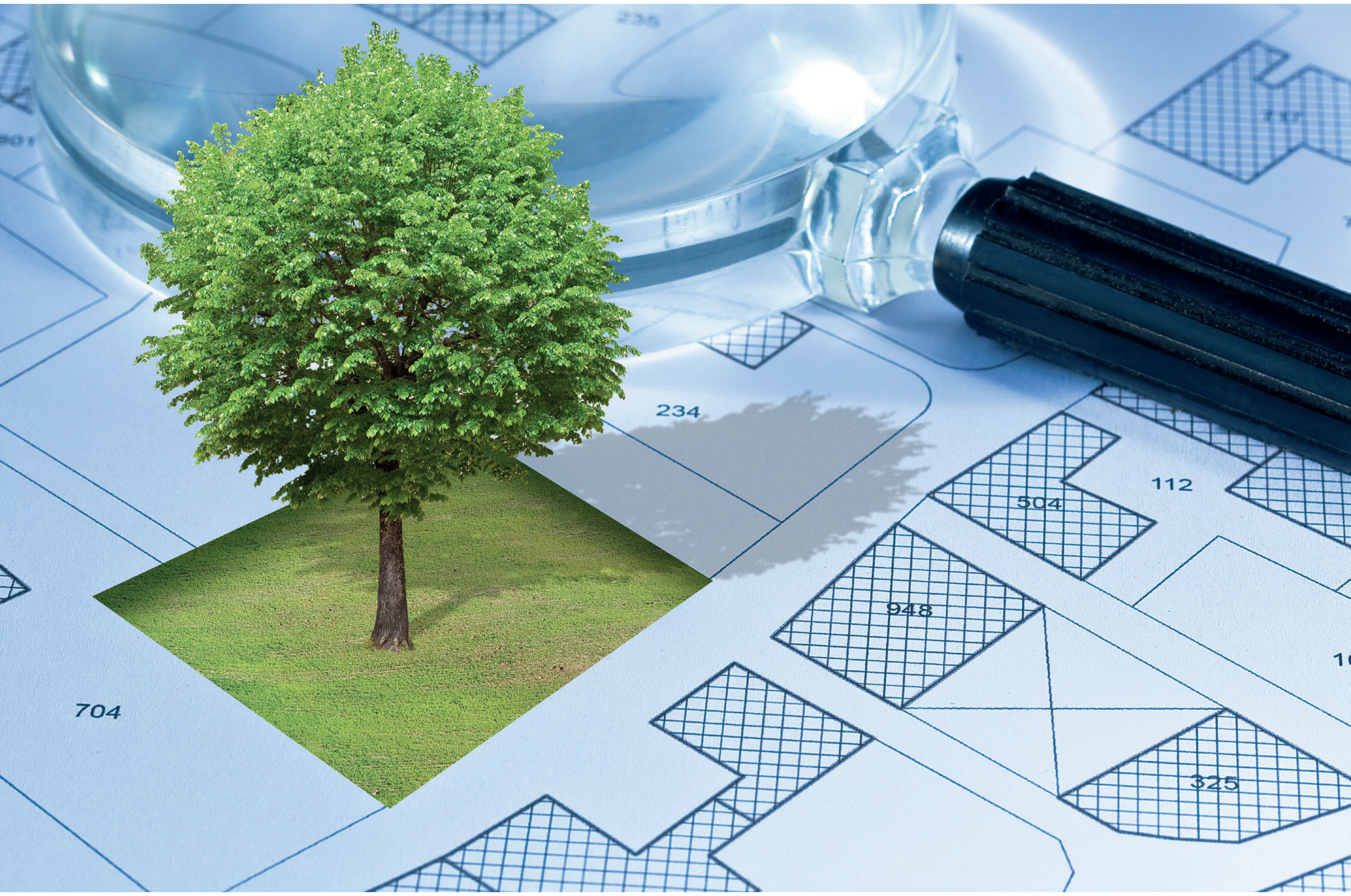
Foster partnerships: Organisations should foster partnerships with suppliers, customers, and other stakeholders to promote collaboration and build greater resilience in the supply chain.

Adopt digital technologies: Adopting digital technologies, such as blockchain, AI, and predictive analytics, can help organisations to automate risk assessments, improve supply chain visibility, and make informed decisions to reduce the impact of disruptions.

Invest in sustainability: Investing in sustainability, including environmentally friendly and socially responsible sourcing practices, can help organizations to reduce the risks associated with supply chain disruptions and promote long-term resilience.

Establish contingency plans: Organizations should establish comprehensive contingency plans that outline the steps to be taken in the event of a supply chain disruption, including alternative suppliers, logistics options, and risk mitigation strategies.

Overall, to make their supply chains more resilient, semiconductor industry organisations should prioritise diversification, real-time visibility, risk management, partnerships, digital technologies, sustainability, and contingency planning.



Our advice to start-ups:
Build up your ecosystem

Olivier Rousseaux

Mathijs Zandbergen

Two imec experts on both sides of the Atlantic take the pulse of deep-tech venturing.

BY OLIVIER ROUSSEAUX, DIRECTOR OF VENTURE DEVELOPMENT TEAM, AND MATHIJS ZANDBERGEN, SENIOR STRATEGIC PARTNERSHIP MANAGER, IMEC

OLIVIER ROUSSEAUX, director of imec's venture development team, and Mathijs Zandbergen, senior strategic partnership manager, are based in Leuven, Belgium and Boston, USA, respectively.

One of their tasks is to support deep-tech start-ups and scale-ups on the turbulent journey from idea to product. That makes them the ideal partners for a discussion about the worldwide deep-tech venturing landscape. Starting from the beginning …

What is deep tech?

Olivier: "Compared to digital innovation, deep tech is a whole new ball game. While the digital revolution changed a lot of things, it left the essence of classic industries such as automotive and energy untouched. But almost ten years ago, that began to change. Disruptive changes in the world of hardware – mostly at the nano level – are profoundly transforming other industries. The automotive sector is probably the best-known example. Not only are cars now filled with software, which basically makes them computers on wheels. They're also undergoing a fundamental transformation due to the integration of advances in material science, such as massively improved batteries. And more compact, energy-efficient sensor hardware is one of the main drivers behind autonomous vehicles."

"The changes in other industries will be even greater. For example, consider how our ability to engineer at the molecular level can transform personalized cell therapies. Or how we could revolutionize agriculture by reproducing the cells or active substances we need in a controlled environment – much like a datacenter, instead of breeding the whole plant or animal."
"Disruptive changes in the world of hardware – mostly at the nano level – are profoundly transforming other industries."

Mathijs: "Thinking about the possible intersections of nanotechnology and industry verticals makes your head spin. The next wave in consumer electronics – AR and VR – would not be possible without the fundamental hardware technologies that, for instance, our own spin-off MICLEDI Microdisplays is working on. And let's not forget the massive changes that are happening in computing itself, where we are shifting to completely new paradigms such as quantum computing. It's not even clear how we will exploit that enormous increase in processing power."

Olivier: "Indeed, the changes that deep tech can bring to society are often beyond our imagination. And that has profound implications at the business level. From that standpoint, deep-tech innovations typically come with a two-dimensional risk. First, there's the technological risk of not being able to solve the scientific or engineering challenge that defines your solution. Remember, we're talking about tampering at the molecular level, leveraging the fundamental laws of physics – so success is far from guaranteed!"

Mathijs: "To me, that elevated technology risk is the biggest difference between digital and deep-tech start-ups. For one thing, it leads to longer development timelines and higher investment needs."

Olivier: "Exactly. But even if they manage to crack that technological nut, start-ups must still overcome the business risk of creating a market that doesn't yet exist – simply because it's beyond people's imagination. To me that's the second make-or-break moment in the evolution of a deep-tech start-up.

It's often also the moment where it needs to transform its DNA, even going so far as changing key C-level leadership positions. Because who originated the idea rarely has the skills to successfully bring it to the market."

> "It's not just about good ideas, but also about good money, good people and bringing it all together."

Mathijs: "It's one of the first things I try to find out when I evaluate a start-up: which stage is it in? Because the answer is crucial to figuring out how imec can help them. In a first phase – for example working on a proof of concept – a deep-tech start-up team needs to focus on proving that the technology works. At the same time, some need help with coaching on the business side. The most successful start-ups hire new talent with new expertise as they grow and have an ecosystem of support for venturing and technology scale-up."

Olivier: "With our venturing team at imec, our aim is to disrupt new and emerging markets with fundamental imec innovations that can be gamechangers in the industries we target. To achieve this, we support deep-tech start-ups by thoroughly understanding their market, writing a business plan, shaping a team. Through this process, the start-up gets to validate and refine its value proposition as well as the technology requirements."

"One of the first things I aim to find out when I evaluate a start-up, is which stage it's in. The answer is crucial to figuring out how imec can help them."
Deep-tech venturing: Europe vs US
Between technology risks and uncertain market opportunities, it's no wonder that, for deep-tech start-ups, failure is more likely than success. And that finding the necessary funding can be a struggle.

Olivier: "Remember, deep tech often happens at the intersection of technology and a certain industry vertical. That means that investors also need this mix of technology and market knowledge. And that's rare. Especially in Europe, the bulk of capital is in the hands of people with high-level financial and market knowledge, but a lack of deep technical knowhow. That's one of the things we want to remedy with imec.xpand: it's the kind of knowledgeable deep-tech investment fund that we think Europe needs more of."

Mathijs: "Here in the United States, the situation for deep-tech start-ups is easier. Capital flows more freely – there are of course also no literal borders. And then of course there's the fabled entrepreneurial mindset. You know, the ideas that come out of European research centers and universities have the same potential as those from their counterparts in the US. The difference lies in the culture. In America it's fine, even expected to

take risks and fail. And then try again until you are finally successful."

Olivier: "I couldn't agree more. It's not just about good ideas, but also about good money, good people and bringing it all together. And that's where Europe still struggles. In the US, it's common for a person to present 40 slides in a meeting and walk away with 10 million of seed funding and 60% of the company shares. That's what we need in Europe: the habit of encouraging and rewarding people who want to take risks."

Seek out support from the start

High risks for high rewards. That seems to be the essence of deep-tech venturing. But Mathijs and Olivier insist that it's anything but a game of roulette. There are ways to reduce the risks from the very start.

Mathijs: "My best advice to start-ups is: build up your ecosystem. That's obvious for tackling the technological risk: deep tech needs a lot more infrastructure than a few tech wizards with laptops. Even if you're 'just' making a dedicated chip (ASIC), you need access to design tools and IP blocks – and therefore external partners. Also, think beyond that very first stage of developing a prototype. How will you move to low-volume and then high-volume manufacturing? Taking that into account from the start can save you a lot of time and costs in the long run."

Olivier: "The road to industrialization is frequently overlooked by deep-tech start-ups. The groundbreaking character of their solution often relies on a microdevice based on advanced semiconductor technologies: added materials, extra layers, slightly different etching. Developing such a prototype is feasible with relatively limited infrastructure such as a university lab.

But when you need to manufacture that in low volumes to serve your first customers, there's not one commercial foundry that will clear out a place in its schedule for you to work out the process. It's better to move your development as quickly as possible to a pilot line with industry-grade tools."

Mathijs: "Obtaining support from the very start is just as important for lowering the business risk. If you wait until after the engineering phase to define your market and look at the competition, you're often too late. The biggest danger is that you're stuck with an overengineered product because you've overestimated the market need. Unless for truly transformative innovations such as quantum computing, it doesn't matter how good your product is, people will not pay for it if current solutions are good enough."

Olivier: "Deep-tech start-ups often focus on one part of the science. And they convince themselves that this will be enough to conquer the market. That's a trap. When it comes to assessing the market value of your solution, don't look at the technology but at the system. Making a component that's five times faster, uses ten times less energy or is two times smaller, does not necessarily mean there's an equal impact on the total system or the end-user experience. That system view is one the perspectives you're missing if you only look at your project through the eyes of the inventor. Involving others to expand that view is the best way to increase your chance at success."

Want to grow you deep-tech start-up?

- Imec supports you at different stages: Early on, our venturing team helps you to understand the market, write your business plan and attract the right mix of technical and business talent.
- Imec.xpand, our deep-tech investment fund offers financial support for solutions that incorporate imec technology. We can also put you in contact with our network of potential investors.
- Do you need a proof of concept or prototype to validate your technology? Imec.IC-link can help you to develop and prototype your ASIC. For products that rely on beyond-standard technologies, you can get enter into a collaboration with our R&D teams.
- Ready to scale up? Imec can help you to get access to commercial foundries.

Customer collaboration crucial for productive change

Mark Andrews, Technical Editor of Silicon Semiconductor magazine, speaks with **ALEX SMITH, VICE PRESIDENT MARKETING AND OPERATIONS AT EDWARDS VACUUM.** The conversation covers Alex's leading role in focusing on the company's sustainability, performance enhancement and optimisation objectives, all of which contribute towards the semiconductor manufacturing industry's growing circular economy momentum.

MA: *IC manufacturers, semiconductor manufacturers, were challenged like never before during the pandemic. We are now in the COVID-19 recovery phase, but we're still dealing with reverberations across the supply chain. Could you please describe the challenges and needs that Edwards Vacuum sees most often with their customers operations these days? In other words, what do they need help doing, are they struggling with certain things?*

AS: The biggest challenge in our industry is the demand for more chips, and all the predictions see that continuing. It's a good problem to have. The semiconductor shortage has also been helpful – I think everybody now understands what we do for a living. But it really faces a lot of challenges. Making chips, especially the advanced ones, is not easy, it's technical, it's difficult. The manufacturing process comprises a complex, widely distributed supply chain. So, it's going to take time, and it's going to take money, and it's difficult just to expand capacity. We've also got a long history of ups and downs within the industry.

These were levelling out a little bit just before COVID. But then when COVID hit, it really showed the vulnerabilities in our supply chain, and these are now being compounded by other things like geopolitical developments, cost challenges - pure volatility. It's just completely unpredictable at the moment, and we need to get back to stability. And there's now another layer to this challenge. There's a growing awareness of the urgent need to see what we can do to combat climate change. Compared to some industries, ours is not a huge direct emitter of greenhouse gases, what we call scope one emissions. But we are a large consumer of power, both in our manufacturing processes and in the use of our products by our customers. This makes our scope two and our scope three emissions quite large. And then, beyond these practical reasons, we've all got to live in the world we're helping to create. We have ethical and moral obligations.

Many of the challenges our customers face are not really tied to recent events like COVID, geopolitical events, or the climate change that we've already discussed. They've been around for as long as the industry has existed and include constant pressures to minimise planned and unplanned downtime, to maximise tool availability, and to get more for less from the supply chain, all at the lowest environmental costs. In the past, it's been, I think, quite easy to overlook the critical systems we have in the fab that enable the process – things like vacuum pumps and abatement systems. But trust me, this is really changing. Customers are really coming to appreciate the significant role that these systems now play in optimising and reducing the environmental impacts.

MA: *It is amazing, isn't it? I like to think of it as out of sight, out of mind. When you go on the production floor, you have no idea, unless you know how a plant is laid out, that almost every tool you see on that floor has a vacuum and abatement system, in most cases, underneath it, in the subfab. Well, what do you see as the best way to resolve customer issues and close that gap, if you will, between where they are and where they need to be according to whatever measure that you think is relevant?*

AS: Of course, the only measures that really matter are the customers' measures. We often refer to those as fab metrics. We collaborate very closely with our customers to understand their issues and their challenges. And that really is the fundamental first step to resolution. We get to understand what the challenges and the problems are. If we use fab metrics as our ultimate measures as well, then it means we're really aligned with our customers problem statements. So that in turn means we're always working on solutions to their problems. And that's really important. We absolutely must be solving their problems.

To give a more direct answer, fundamentally, fab metrics measure performance in key areas like safety, quality, delivery cost, people, and environment. Semiconductor manufacturing is arguably the most complex and demanding industrial process ever developed. And although the process is pretty much the same everywhere at the highest level, it really is remarkable the differences that we see among manufacturer when you get into the details – new tools, new processes, every new material brings specific challenges. But we can always align with our customers' challenge through these high-level fab metrics.

And that's the key. We can always make a tangible link through those fab metrics. Our products sit at the outlet of most process tools where we're tasked to extract process gases and by-products and render them safe for release or disposal. It's only by collaborating with our customers that we build the trust needed for them to share and collaborate in addressing their specific challenges. The more closely we can work with them, the more they'll really appreciate the value that they can derive from our domain expertise in all these areas.

MA: *Today's semiconductor manufacturing environment is more dynamic than ever, as you have just mentioned. They deal with these incredible necessities, like constant product evolution. People outside the industry don't necessarily realise that they're constantly pushing new designs through. The way I like to think of it is that, just when we get the recipe just right for this generation of device, we're moving on to the next. You're redoing it. What can semiconductor manufacturer really achieve? We hear the term circular economy a lot in this regard. Should that be the goal, or do you think it's more about sustainability?*

AS: I think sustainability is the goal and circular economy is one of the ways to achieve that goal. An environmentally sustainable manufacturing process is one that really achieves the immediate goal, manufacturing a product without damaging the environment. In terms of the value created in the product, a circular model is a way to approach sustainability by thinking about potential to reuse, remake, and recycle the product or its components at every point in their life cycle. So, yes, circular economy and sustainability can and should be pursued simultaneously.

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MA: *Do you think now really is the right time to embrace change? Because some people would argue that we're dealing with so much right now, we just want to get back to normal and then we'll talk about the future. But is that really proactive?*

AS: Yes, I think the time really is now. It's become really apparent, I think, that if we don't take any action, there will be some pretty disastrous effects. So, by any calculation, the cost of ignoring climate change far outweighs the cost of taking action to stop or even reverse it where we can. And I think the longer we wait, really, the higher the cost of the inaction. I think that's where I'm at with it. I think, we have got to act now, and we must move quickly.

MA: *I think, and I certainly agree, about the impacts of climate change. For those of you who don't know, I'm based in central Florida. And right now, as this interview is taking place, hurricane Ian is bearing down on us. Now, for those of you who aren't familiar with tropical cyclones, they don't usually grow rapidly in intensity the way this one has. It went from a minor storm to a killer storm in the span of 24 hours, and everyone is attributing this to the fact that the waters are hotter than ever before. And that's what fuels any kind of a tropical cyclone. You may not live in Florida, but trust me, when that storm hits, or the next time your forest catches on fire, or whatever it is that matters the most for you, you will see the impact. Do you think this will change how the product is conceived, some of the core processes? Or is it more about working hardware and the way that we use our hardware to make it more efficient?*

AS: I think it's both. I think there are definitely gains we could make in the hardware, and we do that. I think that's one thing that the organisation really strives to see. How can we create products that are more efficient than any of their predecessors? And that's important because we can then show that pursuing circular economy and sustainability drive does not really add cost. Actually, we can often help to reduce cost, that's really the benefit. Right, so energy is expensive, power is expensive, and it's not likely to become any less expensive, certainly not in the foreseeable features. Reducing that power consumption, reducing the operating cost, really is going to go straight to the bottom line. While improving profitability it also reduces the scope two emissions – greenhouse gases that are generated by power suppliers. Clearly one huge step forward for our industry and for everyone would be if we could move to renewable energy sources. That's something everybody in the industry and in the world needs to collaborate to achieve.

MA: *When you look at the advances being made by some of the major retailers, for example Amazon, they're converting all of their warehouse operations to green energy over time. And considering how big that company is, it's going to have a definite impact. Do we think then that sustainability can be part of an incremental program. Must you take baby steps at first or is it better to jump in with both feet?*

AS: I think it's tough, and it depends a little bit on where you're starting from. The important thing is everybody gets on board, and you have got to work out the pace at which you want to go. But it requires a shift, a massive shift. Moving to circular models and circular design, you have got to start with modular design and then you've got to see how it fits in with a circular economy model. So how do you move from the old make, use, dispose approach to the new make, use, reuse, remake, and recycle model? It's a new attitude, it's a new mindset. And really, manufacturers and industrial organisations must embed this in their business models. That's a really key element, and I'm an optimist here. I look at the progress we as a society have made, what progress businesses have made in the last decade, since we started to take climate change a lot more seriously. Now we can look around and read about things on a daily basis where we see either new initiatives or innovative technology that we think can really make a difference.

As an added benefit, most of these innovations can and will offer real commercial opportunities.

Here at Edwards, we've tried to find the opportunity everywhere that we look with these new innovations. How can we build on what we've been doing for many years? For us, our circular economy journey started years ago, even decades ago. Our service teams, for example, have been remanufacturing our products for decades. And this was our proven circular service business model. With this model, we keep most product life cycles well above ten years. Then we have product upgrades that extend the use and the reuse opportunities, and that can extend the performance capabilities of our products within existing fleets. That's the interesting part. It comes to your question of how do you start? You start quick, you start slow, I think it depends on where you are in your journey. And we were lucky that we had a good foundation of circular principles already. Many of the developments we've had in more recent years have been around smart manufacturing and digital advances. Through advanced data analytics and machine learning, we can now predict machine performance, lifetime, and maintenance requirements.

Not only has this helped eliminate unplanned downtime and productivity risk, but it enables the creation of new sustainability business models, and that provides and enables clear environmental improvements. Our business models need to be underpinned by results, and they need to focus on the customers' needs, not just our capability. Objectives like eliminating product loss, improving tool uptime, reducing unpredictability, preventing disruptions to operations, all of these things are really critical. But now we can also tie in lower costs for energy and consumables, machine optimization, and less waste. These new models allow us to be true partners and to co-manage our customers' risk.

MA: *You've mentioned a couple of times now about working in close partnership with your customers. I understand, coming from the industry, that semiconductor manufacturers can be rather hesitant to share details about their operations, even with trusted vendors with whom they've had successful relationships for many years. Is that a major issue to overcome - that idea of trust and collaboration and working closely and openly with your major vendors?*

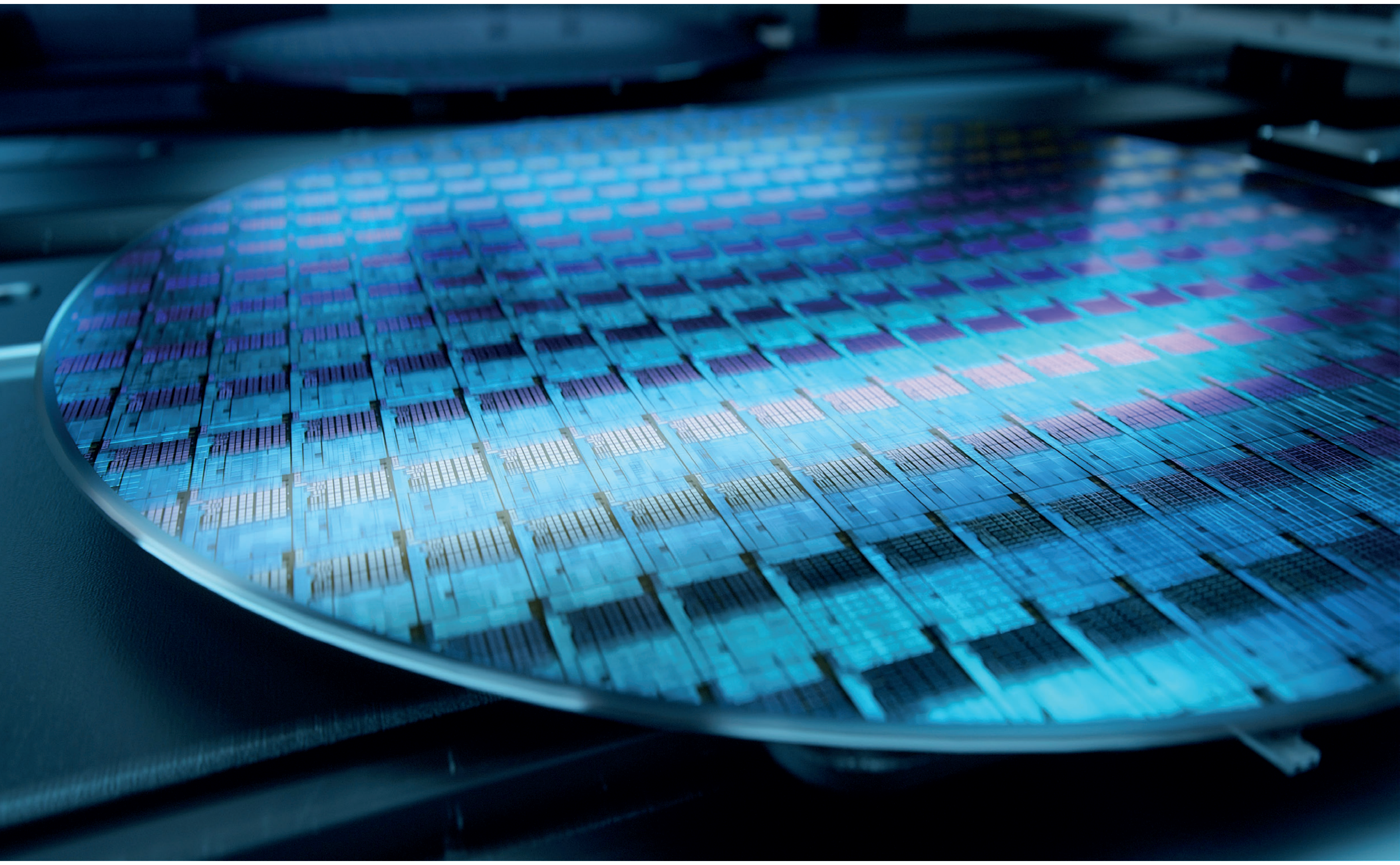
AS: Yes. We approach this by starting small. We develop and test small scale solutions in collaboration with our customers and focus on solving a specific problem. This allows us to learn what resonates with the customer. We know customers are sensitive about their information and sensitive about their data, but when we can build trust and demonstrate tangible value from sharing data we have found a lot of success. When they see real benefits –reduced cost of ownership or reduced risk – from sharing data and information and collaborating with us, trust and openness grow naturally. As a result, we're starting to have success.

In the last two years we've really started to scale these models and solutions in various fabs at very different lifecycle stages to solve a multitude of different problems. And it's all progressed rather rapidly into a comprehensive program.
It requires a holistic approach, definitely collaborative and definitely solving customer problems, but where we can effectively integrate technology, process, and people using the principles of circular economy, we've really got a proven solution, ready to deploy.

MA: *It sounds as if someone who realises this need and realises the opportunity, especially if they've been pressed by their facilities management about cutting down their electrical costs or other issues, needs to act. Whether their motivation is altruistic or really bottom line driven, they should talk to you about getting started - if they aren't already engaged in some kind of a program to make their systems more responsive and more efficient? That's a good way to begin, to give Edwards a call?!*

AS: Absolutely. We really are engaging with all of our customers, and we want them to join the journey with us. We want them to be collaborating with us, we want to co-manage their risk. And we want to be their partners through this. And I think that we absolutely have some solutions and some examples that really show the value added. We believe the time is now for the whole industry to start collaborating.

Let's embrace the principles of circular economy in new business models. Together we can create a sustainable and more profitable future for everybody.



Semiconductor manufacturing analytics maturity: common barriers and methods to advance

Analyzing an operation's current level of analytics maturity requires a thorough assessment of the hardware, analytics software and data management practices.

BY YUJI MINEGISHI, GENERAL MANAGER, GIGAPHOTON INC.

IMAGINE a manufacturing line in which every tool and every process, including the interactions among them, were being optimized automatically for precision, accuracy and speed.

What if you had a data clean room, where data pertaining to every process and tool in the production line was ready to use — standardized and clean — and you could quickly apply any artificial intelligence (AI) model to any data set across every process and tool? What if equipment could notify you when servicing is due, or alert you that a tool in the production line might fail before you complete your process?

This could be the fab of the future. More and more, advanced analytics and Industry 4.0 solutions are being recognized as the key to increased uptime and yield improvement in semiconductor manufacturing.

An analysis by McKinsey calls advanced analytics "the next leap forward in semiconductor yield improvement," and a recent report by Deloitte notes that leading Japanese semiconductor manufacturers are already seeing improvements in productivity and yield from using AI to build real-time predictions about errors, equipment failures and more. In fact, that same report noted that AI systems can analyze data thousands of times per minute — nearly 600 times the rate of human staff.

Analytics Maturity is the Key to Actionable Intelligence

For most semiconductor manufacturers, gathering data isn't the problem. Sensor-laden fabs are sitting on enormous amounts of data. What's challenging is the process of turning the data into actionable intelligence (Fig. 1).

Many manufacturers currently rely on labor-intensive manual processes to gather, analyze and visualize data. To set up thousands of charts, watch them and react to them is extremely inefficient. And with hundreds of parameters and the interactions among them to track on a daily basis, manual analytics processes can't keep up; there are simply too many factors to comprehend.

Some chip manufacturers use AI-enabled predictive and prescriptive analytics for certain isolated processes or tools. But according to a recent survey conducted by the light source vendor Gigaphoton, only 26 percent of semiconductor manufacturers have access to this type of advanced analytics. Moreover, there are substantial impediments to achieving AI-enabled analytics integration across the entire production line.

Yet, achieving this level of advanced analytics capabilities is a goal semiconductor manufacturers must work toward to realize significant yield improvement and increased output in the context of increasingly complex manufacturing processes.

The Three Major Barriers to Advancing Analytics Maturity

Investing in Industry 4.0 solutions will help improve performance and efficiency, but turning an operation into the fab of the future can't happen overnight. To achieve a more advanced degree of manufacturing analytics maturity, it's important to know where the greatest impediments lie. Typically, barriers to achieving advanced manufacturing analytics maturity stem from three sources:

- Hardware
- Analytics Software
- Data Management

In terms of hardware, chip manufacturers typically use a mix of legacy and highly advanced manufacturing equipment, networks and sensors. The capabilities range from mere logging of descriptive data to receiving real-time data feedback and optimizing based on deep vendor-specific intelligence.

When it comes to analytics software, there isn't a standardized platform for semiconductor manufacturing analytics. In fact, survey data reveals that 73 percent of semiconductor manufacturers weave together multiple disconnected equipment analytics solutions to get the information and intelligence they need. It is true that multiple software programs can be a sign of a robust data science program and not a symptom of inefficiency. But simply put, one standardized platform for on-premise semiconductor manufacturing analytics does not exist. Capabilities range from pulling basic data for viewing and manipulation to sending AI-driven feedback to equipment for performance optimization.

With data management it is important to reiterate the point that chip manufacturers have access to enormous amounts of data, but the way it's currently received, stored and accessed often negatively impacts their ability to turn it into actionable insights. Data management solutions range from basic data storage in a single file to vast, frequently updated databases.

A 5-Step Maturity Model Toward Progress

An analytics maturity model recently developed by Fabscape uses the three barriers of hardware,

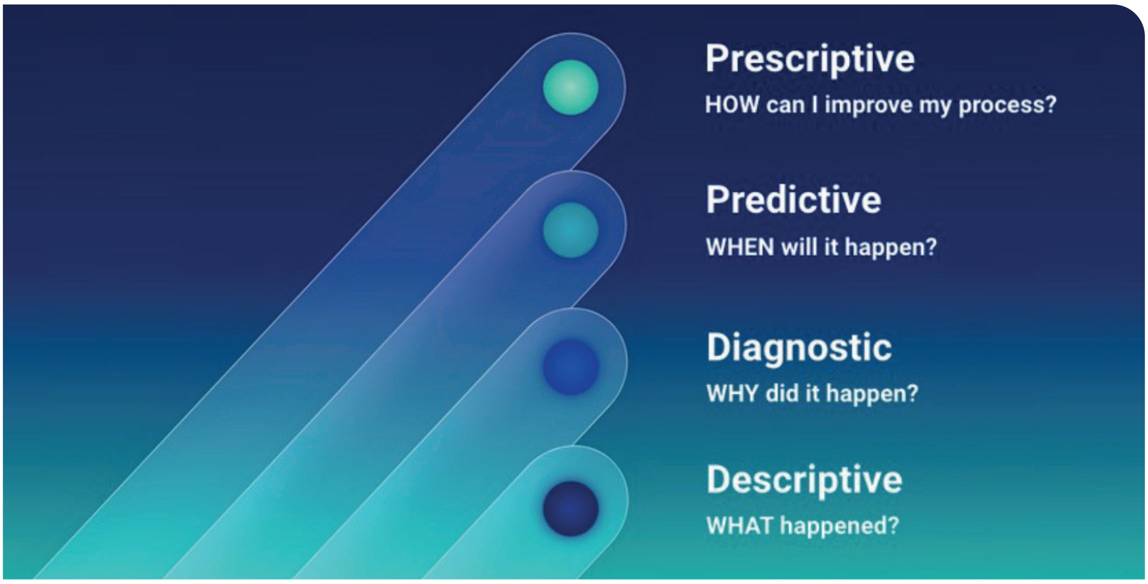


Figure. 1: The four levels of possible insights provided by analytics tools range from descriptive to prescriptive.

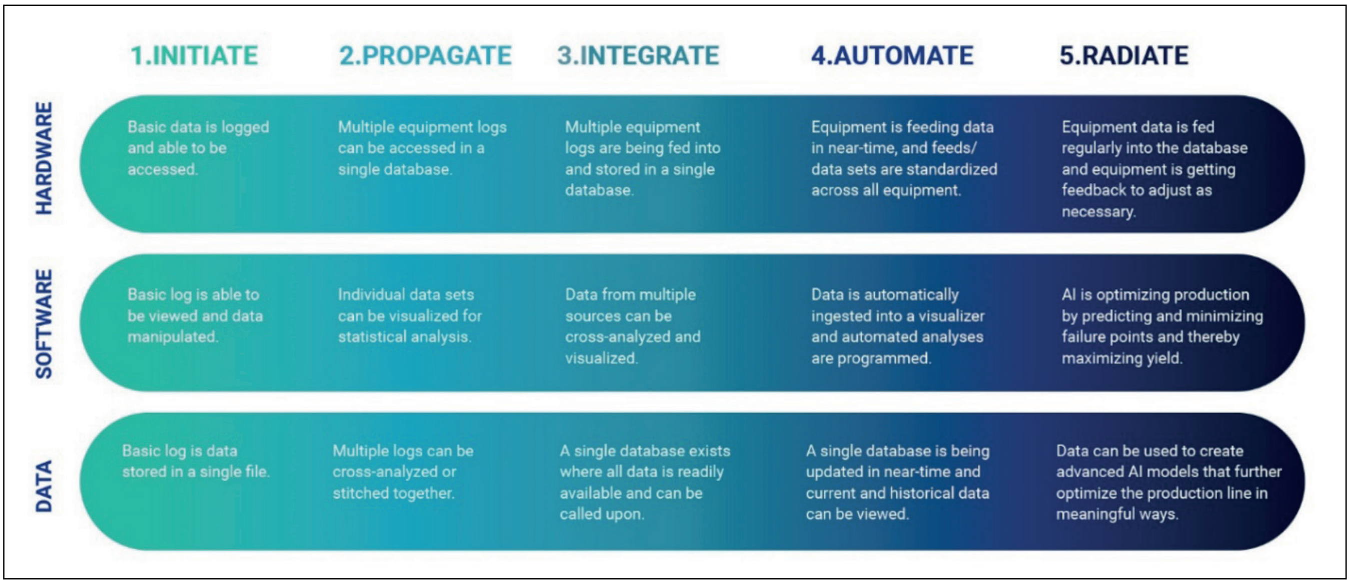


Fig. 2: The semiconductor manufacturing analytics maturity model developed by Fabscape aims to help chip manufacturers conceptualize progress toward advanced analytics.

software and data management as a jumping-off point and further defines analytics maturity progression through five separate stages:

- Initiate
- Propagate
- Integrate
- Automate

Radiate

Figure 2 illustrates that a manufacturer whose operation falls within the "Initiate" category is at the most basic level of analytics maturity across hardware, software and data. Only the most rudimentary data is logged within the simplest possible file formats, and processes are highly manual and ad-hoc.

On the other end of the spectrum are manufacturers who are at the highest level of maturity advancement, or the "Radiate" category as this model describes them. These are manufacturers who are already optimizing production with streamlined data collection, automatic equipment adjustments and advanced AI modeling techniques. Even the most elementary semiconductor manufacturers can log, access and manipulate basic equipment data that is stored in individual files (e.g., CSV, XML, etc.). Yet to be truly successful, modern chip production needs to leverage more sophisticated techniques to gather, analyze and manage data.

> Analyzing an operation's current level of analytics maturity requires a thorough assessment of the hardware, analytics software and data management practices

This is where the power of AI truly shines: by developing advanced AI models, chip manufacturers can quickly trace failure points, optimize production and ultimately increase yield.

Identify Where an Operation Lies on the Maturity Scale

Analyzing an operation's current level of analytics maturity requires a thorough assessment of the hardware, analytics software and data management practices. The end goal of such an analysis is to identify gaps and opportunities that will enable a manufacturer to move away from analytics practices that are descriptive and diagnostic, and toward advanced analytics that are predictive and prescriptive.

Semiconductor manufacturers seeking help in identifying their current maturity level and the associated opportunities can take the maturity assessment designed by Fabscape. By answering approximately 10 questions, survey respondents can learn where their operation lies on the maturity scale of 1-5 and receive tailored recommendations for next steps to advance their analytics.

Plotting where an operation is on this maturity framework can help manufacturers think about how they are currently using data to drive actionable insights and optimize systems. The journey may not be linear for some, but it is critical that chip manufacturers fill important gaps and develop a roadmap to achieve advanced analytics maturity.

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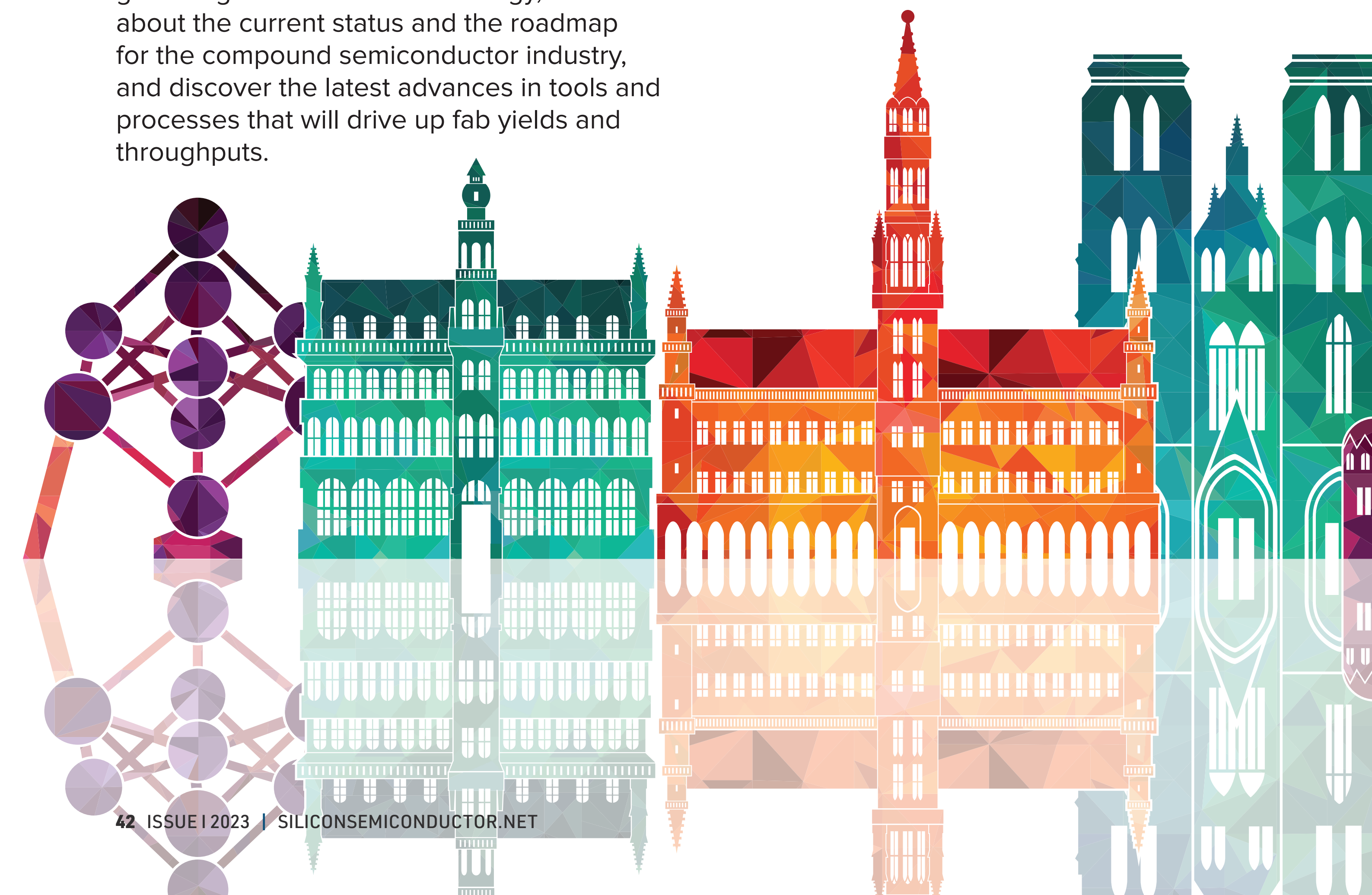

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Improving yields, cycle times and overall equipment efficiency

MARK ANDREWS, TECHNICAL EDITOR OF SILICON SEMICONDUCTOR MAGAZINE, SPEAKS WITH DAVID MEYER, CO-FOUNDER AND CEO OF LYNCEUS. The company's AI/ML modelling system integrates into a semiconductor foundry or IDM to analyse fab data in real-time. The resulting actionable insights help to identify manufacturing problems sooner, solve them faster, achieve process efficiency and improve operational sustainability.

David Meyer, Co-Founder and CEO of Lynceus

MA: *Perhaps we can start by considering how manufacturers work now, and how a product like the Lynceus system can be used to help them work better, more efficiently and without errors that lead to defects?*

DM: Lynceus provides an accelerated "time to action" between a typical semiconductor manufacturing process and one enhanced by Lynceus. In a typical manufacturing environment, the process engineer needs to wait hours for the results of physical metrology before being able to take action.

With Lynceus Argo and our predictive ML models, the engineers are notified of any excursions in real time, and can take action immediately instead of hours later. In addition, unlike physical metrology, Lynceus ML predictive models run on every wafer manufactured, not just on a sample of wafers produced, so manufacturing visibility is increased to 100%. So, manufacturing defects that may not be present in a sampled wafer, but are present in a non-sampled wafer, would be detected by Lynceus but missed by traditional physical metrology.

MA: *How does the Lynceus system differ from what's currently available? In other words, would you compare how a 'standard' MES operates and what it can do to reduce or help eliminate defects, and what the Lynceus system can do in comparison?*

DM: Manufacturers currently use two main tools to control their processes:
Physical metrology: measurements of known outcome parameters influencing yield (CDs, etc) which are accurate but operationally disruptive. This means they can only be performed after the fact on a sample of production and therefore provide limited visibility to the process engineer

Statistical Process Control (including more sophisticated but essentially similar tools such as Fault Detection and Classification): application of control limits on known critical process parameters (temperature, pressure, etc) can help detect major deviations in how the process runs but only indirectly correlate with the outcome parameters. This means SPC often fails to flag defects related to more subtle process deviations

Lynceus bridges the gap in quality control by predicting the value outcome parameters for every wafer produced, in effect providing real-time visibility to process engineers over 100% of their production.

In addition, Lynceus includes a diagnosis module that explains every prediction (by identifying which variations in process parameters influenced the model), thereby helping engineers identify root cause much quicker. Lynceus real-time process control therefore helps manufacturers detect failures earlier, optimize physical metrology and accelerate the resolution of issues.

MA: *I guess an obvious follow-up would be to ask why should the semiconductor industry in particular invest in a Lynceus solution as opposed to an alternative one?*

DM: The Lynceus solution is specifically designed for high value manufacturing environments such as semiconductor fabs, while existing solutions are generally horizontal and unadapted to the constraints associated with those environments. Concretely, Lynceus prioritizes the actionability of its solution over anything else - which boils down to 2 key elements:

- Robust predictive performance
- Actionable signal

For a model to be predictive in production conditions, it needs to remain accurate across a variety of different product and tool types, and over time (retrain a model every hour is not realistic). This means it needs to be able to generalize well from limited, highly unbalanced data which is a difficult task. Lynceus uses patented, proprietary modeling techniques in order to build and deploy the most robust models on the market.

This being said, even an accurate model is useless if it is not acted upon. Predictions need to be integrated into an actionable signal able to support production decisions. The objective is to make the life of the process engineer easier, which means the model output must include the context necessary for the process engineer to trust and interpret its predictions, as well as interface with existing out of control action plans. Lynceus combines AI expertise with experience of high value manufacturing environments to deliver a ready to use solution.

MA: *And has Lynceus already secured any business in the semiconductor sector – helping to solve a real-world problem?*

DM: We have been working with a top tier manufacturer of automotive chips to deploy our solution on an etching process, with the objective of providing real-time visibility over the key physical attributes of the isolation trench.

In order to control this process, our customer relied on physical metrology measurements performed on a fraction (c.5%) of production. In addition, given the necessary time to measure those attributes and the associated operational challenges, our customer only measured wafers every few days which essentially means that it took them a few days to detect process deviations. Given that they are producing 24/7, this lack of visibility means every process deviation impacts a significant share of production, resulting in high level of scraps. Deploying Lynceus enabled them to reduce the time

> The Lynceus solution is specifically designed for high value manufacturing environments such as semiconductor fabs, while existing solutions are generally horizontal and unadapted to the constraints associated with those environments

necessary to detect process deviations from days to hours, while gaining visibility on key isolation trench attributes for every wafer. Our customer wass therefore able to decrease the metrology measurement frequency by 4x, thus improving both cycle times and the overall equipment efficiency of their etching tools.

MA: *So, the customer has seen great value in the Lynceus solution? And are there any other benefits that the system has provided this customer, or in more general terms?*

DM: We saw how Lynceus helps manufacturers improve yield, cycle times and overall equipment efficiency at the scale of the single process step in the fab through real-time process control. Deployed at scale, ie over all the critical processing steps in the fab, Lynceus can deliver additional benefits:

Metrology scale down: Lynceus helps decrease metrology sampling frequency at the scale of the single process. At the scale of the entire fab, this could enable manufacturers to reduce their fleet of metrology tools, both reducing the associated CAPEX spend and increasing the floorspace available for revenue-generating equipment. For reference, metrology makes up 15-20% of the processing steps in a fab so the potential savings are very material

Electrical test prediction: Covering all critical processing steps in a fab means providing real-time feedback on the performance of the most important contributor to the device's electrical performance, measured at the very end of the manufacturing process. This means that Lynceus could in theory use data from every major contributing process to provide real-time feedback on the probability of success / failure at electrical test. A wafer typically takes several months to arrive to electrical test, going through hundreds of highly costly processing steps along the way - spotting failures early would represent a step change versus current process control capabilities.

Lynceus bolsters leadership team

LYNCEUS has appointed Asmahe Maadi as Vice President of Finance and Corporate, where she will lead the charge in controlling all internal and external financial categories, execute Lynceus' operational plan and improve bottom line results.

With more than a decade of financial leadership expertise, Maadi most recently served as Head of Finance at Kpler, where she oversaw analytical data for commodities. She has also held roles with leading global corporations, including Spark Commodities, Linkfluence, Sanofi and Veolia. In her new role, she will monitor the financial performance and compliance of the company and bring transparency and strategic oversight to the Lynceus Board of Directors and stakeholders to prepare for the company's expected growth.

"Asmahe is a proven global finance expert who brings a compelling blend of strategic and capital allocation discipline, extensive operating skills and insightful leadership abilities," says David Meyer. "She has a long, well-regarded track record of strong financial capabilities which will be a benefit to Lynceus as we scale our operations."

Maadi's experience spans both multinational corporations and SaaS startups, where she played critical roles in transforming companies into global, digitally enabled leaders across multiple areas. She's operationally savvy in improving strategic and structural change amidst substantial market disruption and reforming portfolios to result in more profitable growth. She holds a bachelor's degree in international business, finance and marketing from the James Cook University in Singapore and a bachelor's degree in marketing, accounting and cost controlling, along with a master's degree in audit expertise comptable from the Paris School of Business, ESG Management School.

"Lynceus sits at a rapid growth juncture, leveraging its best-in-class aptitude and analytical tenacity, and I'm pleased to be joining at a time of significant opportunity for the company's massive growth. I look forward to bringing my experiences in executing disciplined financial management and leadership to support the structure of the company for scale," states Maadi.

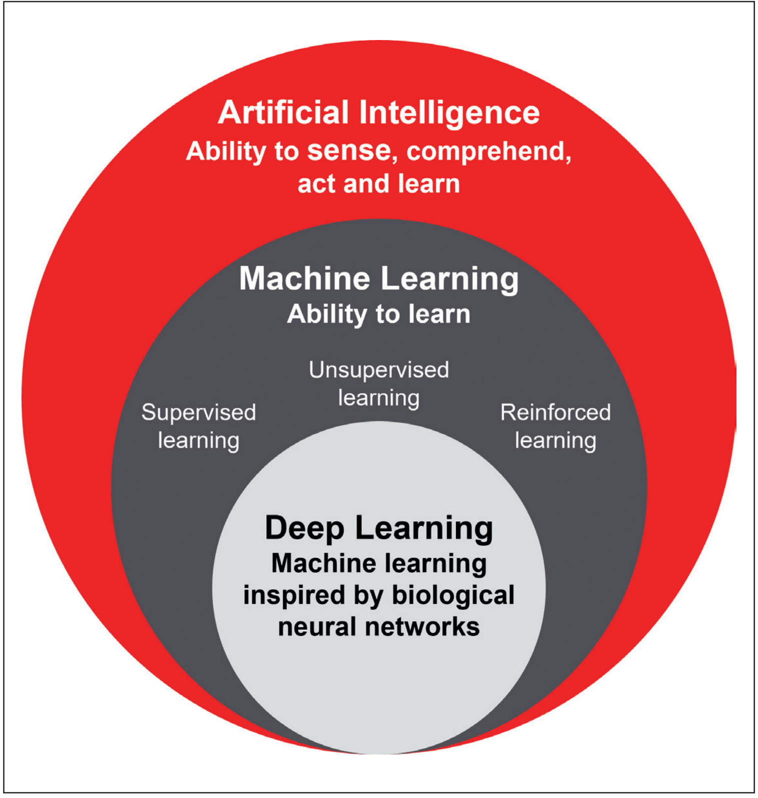
Automating the semiconductor industry: Electron microscopes, AI and ML

To support semiconductor manufacturers' needs to automate, advanced electron microscopes are integrating AI capabilities to provide faster time-to-data and increase the productivity of human and tool resources.

BY DAVID AKERSON, SR. GLOBAL MARKET DEVELOPMENT MANAGER AND JOHN FLANAGAN, SOFTWARE ENGINEER, THERMO FISHER

OVER THE LAST FIVE YEARS, interest in deploying artificial intelligence (AI) and machine learning (ML) applications in the semiconductor industry has grown rapidly. With processes and tools that generate petabytes of data, AI, with its ability to mine and utilize data, offers many opportunities to semiconductor manufacturers as they strive to improve processes, optimize human and tool resources, and automate labor intensive tasks. Among the many opportunities from AI and ML are process automation, tool optimization, fault detection and classification, predictive tool maintenance, metrology, process control, fleet management and many more.

In this article, we will focus on AI and ML and the automation capabilities in electron microscopes for the semiconductor industry, including scanning electron microscopes (SEM), focused ion beam SEMs (FIB-SEM), transmission electron microscopes (TEM) and scanning transmission electron microscopes ((S)TEM). We'll begin with a brief discussion of AI and ML, present the case for automating electron microscopes, and discuss AI/ML capabilities available in today's electron microscopes.



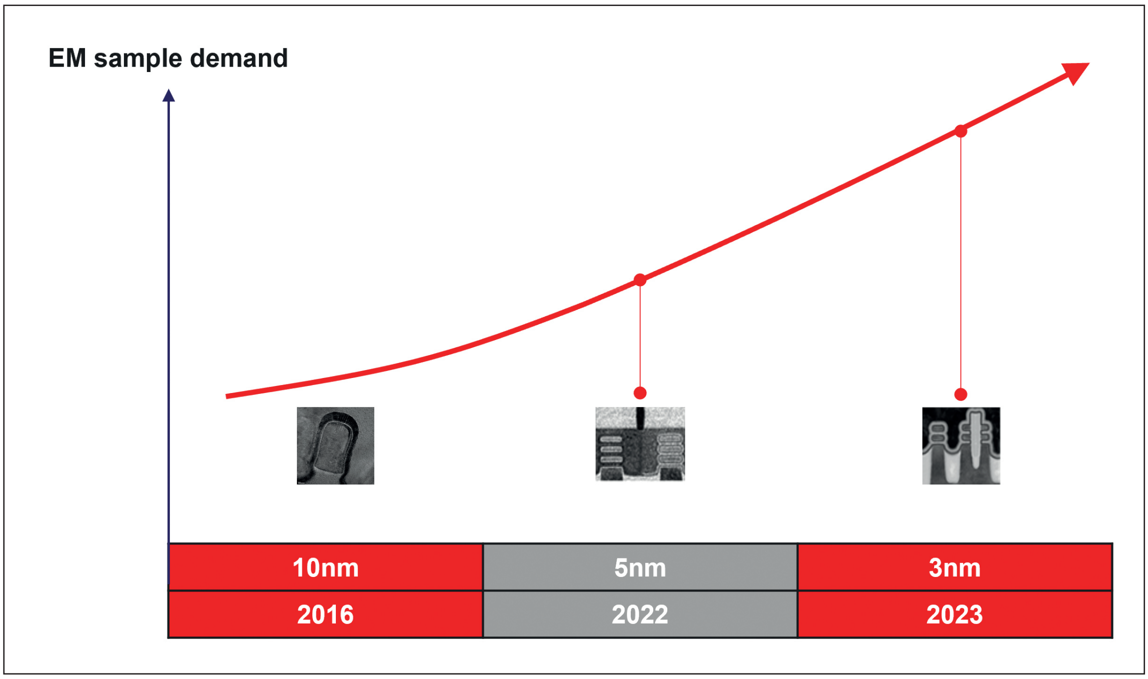
AI and ML

Before discussing AI in electron microscopes, a brief review of AI concepts may be helpful.

At a high level, AI is not a single technology. Rather, it is collection of technologies that together allows machines to mimic human intelligence. AI systems incorporate four capabilities: 1) the ability to sense with cameras or sensors; 2) the ability to comprehend by extracting information, detecting patterns and recognizing context; 3) the ability to act and 4) the ability to learn. Of the four capabilities, learning is the most associated with AI.

While many consider AI and ML as synonymous, the two are slightly different concepts. ML is a subfield of AI and refers to automating learning. For an AI system, ML allows it to sense, understand, assign significance, and modify behavior in an iterative process based on past results against specified parameters to improve performance. ML applications can be descriptive, predictive or prescriptive.

A variety of ML techniques exist grouped into two rough categories: Unsupervised learning and supervised learning.



Electron microscope (EM) sample growth from 10nm to 3nm

Supervised learning requires data labels or annotations, which function as a teacher for the machine learning task. Unsupervised learning seeks to uncover patterns and natural grouping in the data without the need for labels. Since labeling data is expensive and time-consuming, unsupervised learning can be advantageous. However, many machine learning tasks are not amendable to pure unsupervised learning such as image classification. Often these techniques can be combined. The technique of self-supervised learning first learns on the vastly larger bodies of unlabeled data using a task related to the desired task. The ML system is then reconfigured to tune itself on the smaller body of labeled data.

Regardless of the method used, it is important to remember that ML depends on the quality, bias and size of the training data set. Faulty, poorly labeled or incomplete data can result in machine learning bias where, if the AI system is trained in a certain way, it can provide information in an unintended way.

An additional subfield to be aware of is deep learning (DL). DL is a specific type of ML inspired by biological neural networks. DL uses artificial neural networks, which mimic biological neural networks in the human brain to process information, find connections between the data, and come up with inferences. The DL boom kicked off with AlexNet in 2012, where AlexNet produced a quantum leap improvement in the ImageNet classification task, a key challenge in the computer vision field. Deployment of DL further revolutionized the fields of machine translation, speech recognition, protein folding and many more applications.

Finally, it is also important to note that automation can be labor-intensive. Machine learning algorithms need to be trained, possibly with labeled data, requiring a time investment in data annotation. However, once this is done, the algorithms can work well on the target task provided the target/inference data matches the training data domain. If the data drifts, retraining is required.

The Case for Automated Electron Microscopes

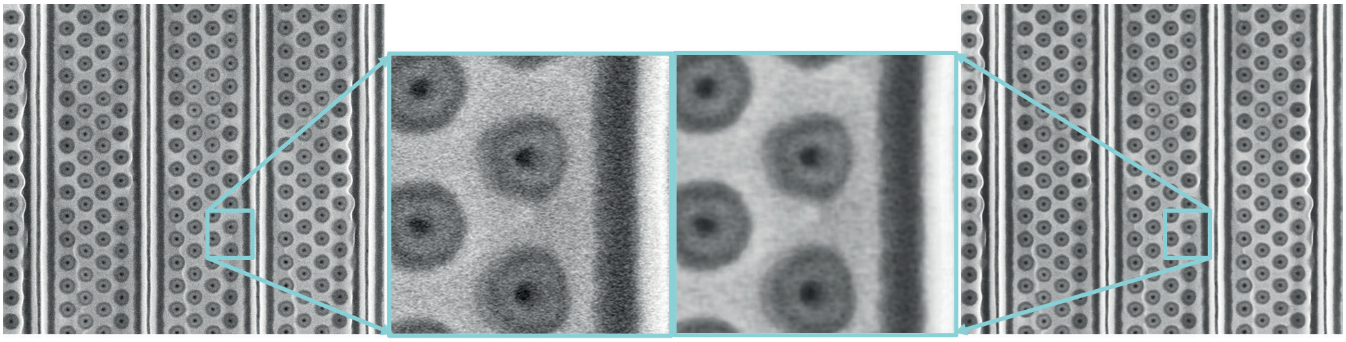
Simply stated, semiconductor manufacturing is among the most complex endeavors ever undertaken. Manufacturing today's three-dimensional (3D) semiconductors requires hundreds of process steps to produce a single chip containing billions of transistors and interconnect lines. As logic and memory move to increasingly higher ratio 3D structures with higher densities, the availability of statistically relevant data with sub-angstrom accuracy has become critical for identifying defects and out-of-tolerance process steps. As a result, advanced FIB-SEM, SEM and TEM tools become critical components for acquiring data in all leading-edge wafer fabrication processes.

Within the semiconductor industry, electron microscopes have, and continue to play an increased role in supplying data to improve and optimize fabrication workflows. Data is extracted from samples for (S)TEM imaging and analysis to calibrate toolsets, diagnose failure mechanisms and optimize process yields. However, prior to performing the highly specific measurements, the sample needs to be prepared with a FIB-SEM, and it should be noted, (S)TEM imaging and analysis are greatly dependent on the quality of the sample.

Historically, the challenging task of sample preparation for SEM and TEM analysis has been performed manually by experienced FIB-SEM users. In the case of TEM sample preparation, this can be particularly time-consuming. However, manual

David Akerson

John Flanagan



➤ 3D NAND channel image without (left) and with (right) SNR image optimizations

processing is quickly becoming unsustainable as the number of samples required to support each successive semiconductor generation's development has grown exponentially and is exceeding available human resources. To provide context, a typical leading-edge semiconductor manufacturer may produce 35,000 to 40,000 samples per month on current process nodes and this number is expected to multiply substantially with the next generation.

Once a sample is prepared, the analytical work begins. Using an advanced metrology (S)TEM such as the Thermo Scientific™ Metrios™ AX, the lab measures critical dimensions and characterizes the device to gain a better understanding of its make-up at the atomic scale. Similar to sample preparation, this task has traditionally been performed manually and can also be time-consuming.

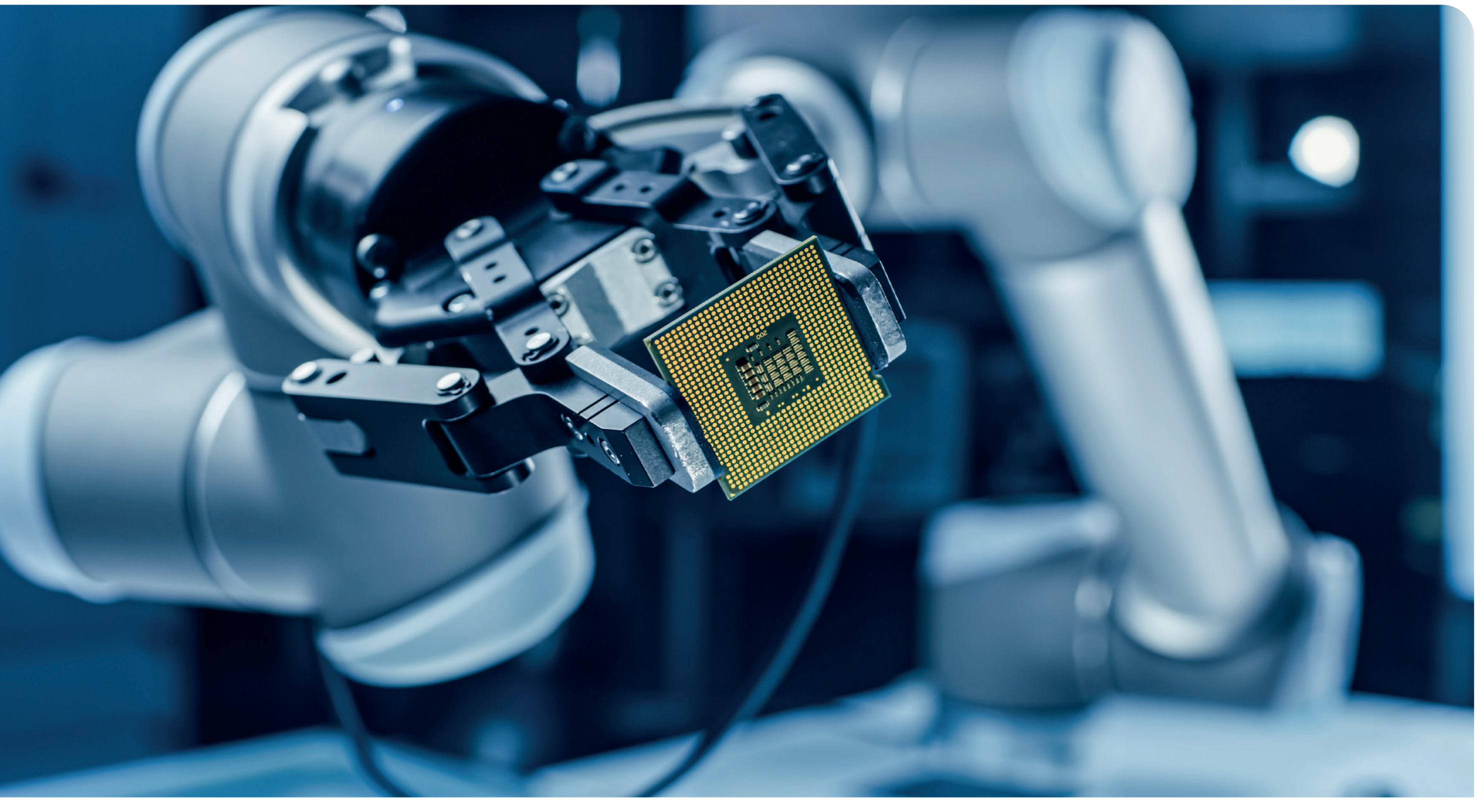
Faced with an increase in the number of samples to be processed and the need to provide information turns faster, many semiconductor manufacturers are pursuing tool automation in the lab and fab. interested in automating tools in the lab and fab.

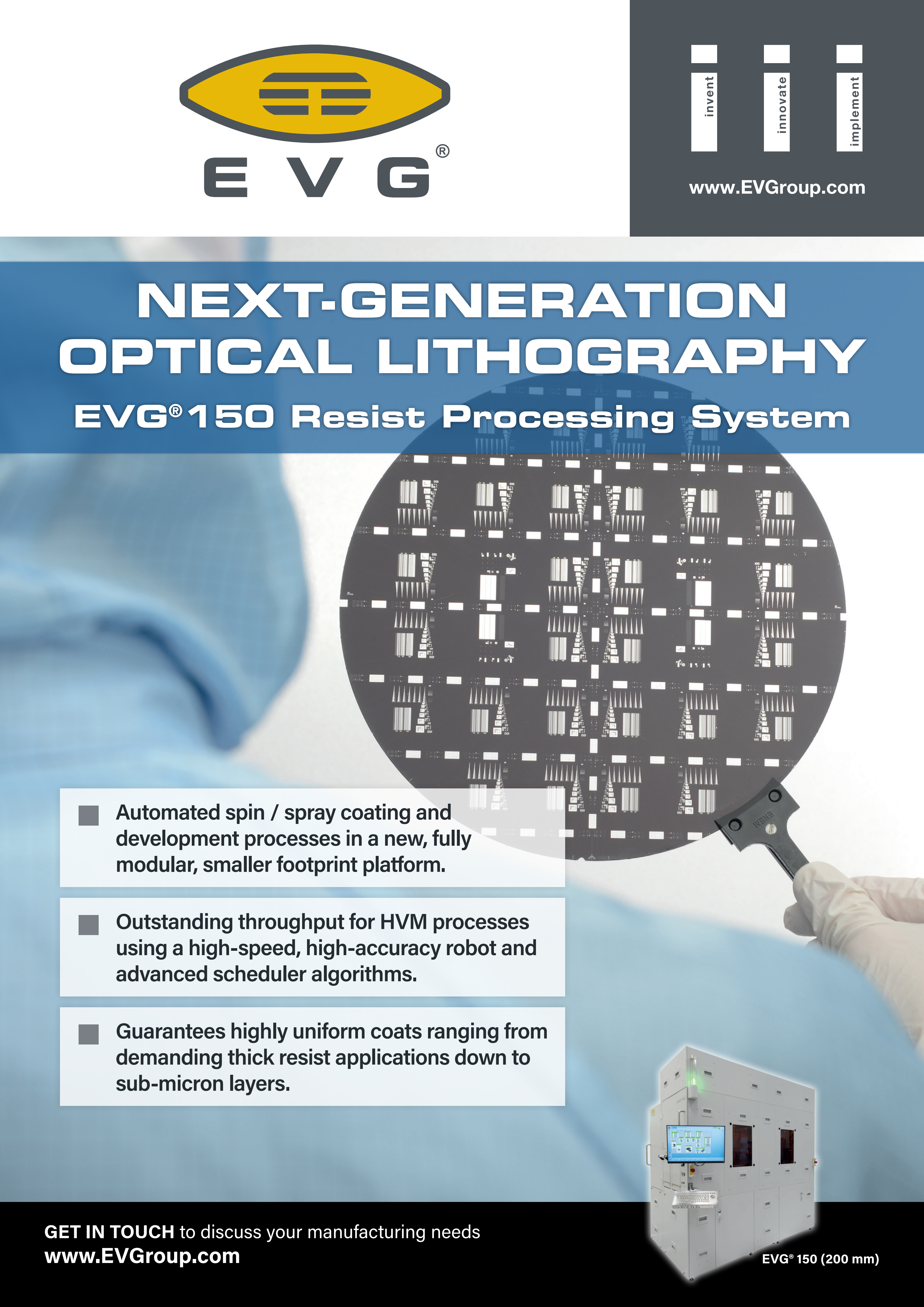
AI/ML in electron microscopes

To a certain degree, the AI capabilities of today's electron microscopes are in their infancy and mainly found in the two areas: system calibration and process automation. A less developed category is data analytics. To provide examples of some AI applications for the semiconductor industry, below is a brief description of some of the AI-enabled capabilities in Thermo Fisher Scientific's (S)TEM, DualBeam and scanning electron microscopes (SEM).

System calibration

System calibration is primarily about keeping the electron microscope in a working state and optimizing its performance. Within system calibration, four of the most widely known applications are tool alignment, predictive maintenance and monitoring, fleet management and image optimization. Examples of these applications follow.

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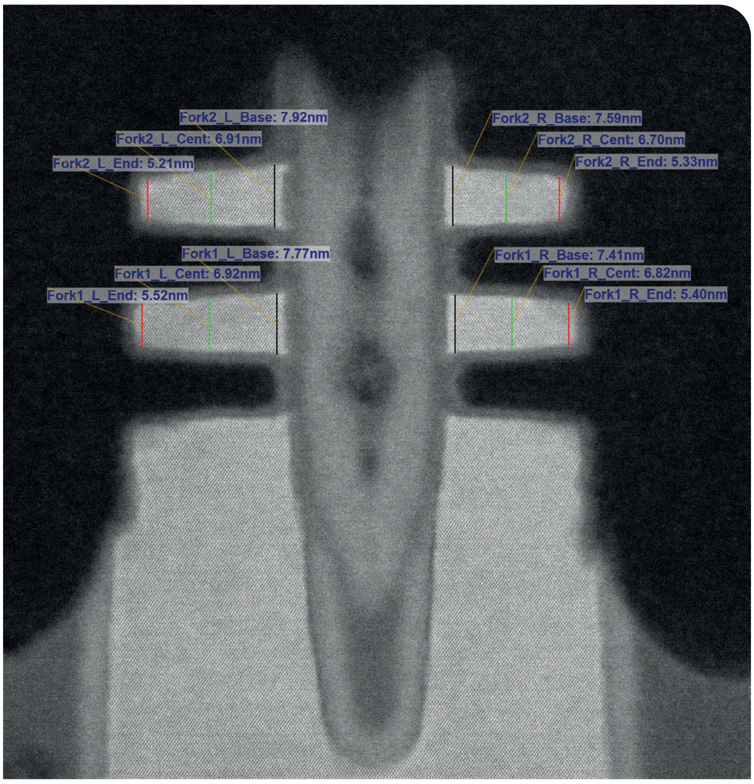

➤ ROI navigation and image acquisition of a GAA device enabled by AI

With tool alignment, the electron microscope utilizes computer vision and advanced algorithms to align the column and the beam. AI tracks the column's alignment state and compares it to the stability window to keep the tool aligned and operating at specification. This ensures high quality data capture and prevents losses in productivity due to runtime errors or excursions found after data has already been collected.

Predictive maintenance and monitoring are enabled by using AI and collected sensor data to automate the identification of potential issues that may impact tool operation. Predictive maintenance and monitoring provide the ability to avoid unplanned downtime, proactively schedule maintenance as required, or be notified to intervene when a sudden failure is imminent.

An additional example of an application in this category is image optimization. For the semiconductor industry, data cleaning or denoising can be of vital importance to produce reproducible and statistically meaningful quantitative analysis of (S)TEM data. In the example below, a ML network was trained on the structures to reduce the signal-to-noise ratio (SNR) and improve SEM image quality and acquisition speed. The images on the right are the denoised images.

Process automation

The goal of process automation applications is to automate the performance of sample preparation, data acquisition and metrology tasks to increase the productivity of workforce resources. Three examples of applications that provide process automation are end-pointing, automated recipe workflows and region of interest (ROI) navigation.

End-pointing detection utilizes ML, sensor and metrology measurements to stop milling when the metal or via layer of interest is exposed. When a specific sensor measurement, feature or threshold is seen, the etch tool is instructed to halt the etch operation.

With automated recipe workflows, "recipes," or scripts are written and utilized to perform repetitive tasks. ML is a recipe component enabling the recipe to adapt to local data.

The final example in this category, ROI navigation, allows detection of specific features to automatically navigate to a ROI. Through this capability, users are able to improve cut placement, define image acquisition areas and enhance the quality of the end data.

Data analytics

As mentioned above, semiconductor data analytic applications are not as well developed as they are for many other industries. While there is strong interest in applications that utilize data insights to drive better choices, a number of factors have contributed to the lack of these applications. One of the key factors has been a sparsity of data. With recent advancements in deep learning, it is creating opportunities for new applications. However, there is a great need for data. In some cases, customer specific data is not required. For others, as large volumes of data are needed, there is a need for collaboration with the semiconductor manufacturer to build a production-worthy application.

Summary

For the semiconductor industry, many factors are coming together that necessitate the need for automation in operations, including more complex designs, longer development cycle times, increased competition and technical resource constraints. As a result, many semiconductor manufacturers are exploring technologies to automate their operations utilizing AI.

AI has the potential to generate huge business value as semiconductor companies develop new products and ramp manufacturing. Benefits include automating tasks to free up skilled resources, improving the performance of tools, optimizing human and tool productivity and accelerating development cycles and time-to-market.

To support semiconductor manufacturers' need to automate, advanced electron microscopes are integrating AI capabilities to provide faster time-to-data and increase the productivity of human and tool resources. While still in its infancy, the AI capabilities in electron microscopes are likely to grow rapidly as manufacturers seek to extract the value hidden in their data.

Enabling hydrogen purification for process equipment

BY ARM PURIFICATION

HYDROGEN is used in many processes in the semiconductor industry, such as annealing, epitaxial growth, lithography, and as a carrier gas for hydride dopants. The use of hydrogen gas in the semiconductor industry is increasing, and along with that increase come constraints on supply chains and markets. Hydrogen generation is becoming more prevalent, as well, in order to mitigate traditional supply chain issues such as trucking, plant shut downs, and more.

It's critical to utilize the right gas purifier when working with hydrogen. Applied Energy Systems (AES), the leading provider of high and ultra-high purity gas delivery systems, is focused on offering gas purification solutions for complex and myriad applications. AES's ARM Purification division recently introduced the redesigned APS60 series of purifiers, including the APS60-CXXX series of hydrogen purifiers (XXX is the flow in Nm3/hr). For any process, ARM Purification is equipped to handle hydrogen purification; traditionally utilizing H2 from liquid, tube trailers, and other sources and purifying it to 8N or 9N outlet quality.

Challenges with Traditional Heated Media-Based Purification Technology

While bulk purifiers have traditionally been utilized on systems providing fairly constant flow requirements, ARM Purification has introduced the ability to provide purified UHP 9N hydrogen gas in a process environment that demands high flow rate variations and fast response times for the success of the process. These systems are sized up to 300 Nm3/Hr and are fully PLC controlled with hydrogen safety features built into the unit.

Using traditional heated media-based purification technology for hydrogen purification is somewhat difficult in applications that require high flow rate variations, such as EPI, due to the construct of the material's reaction towards hydrogen. The traditional purification media, often a metal getter, reacts with hydrogen in a reversible manner, giving the ability to increase purifier vessel pressures and temperatures quickly upon flow demand through the unit. This is because the hydrogen can react exothermically with the media, and constitutes a reversible reaction in the media that is both temperature and pressure dependent.

Unlike oxygenated species and hydrocarbons, which are chemically bonded to the material upon reaction, the hydrogen goes into solid solution and is a reversible reaction. Therefore, under high flow requirements, the temperature increase needed to optimize purification efficiency must be monitored in real time, along with the pressure, in order to control the potential for increases in both, without the pressure loss associated with membrane H2 purifier technology.

Stringent Safety Considerations for Hydrogen Systems

The safety considerations of hydrogen systems are stringent – but with a solution like ARM's updated APS60 platform of purifiers, there exists the ability to automatically purge the purifier system with Argon gas, and provide for a safe system shut down in case of emergency. This shut down is then followed by an automatic process to re-introduce H2 into the media, thus providing a hydrogen compatible media to resume the purification of the hydrogen gas quickly and safely. All of these processes are PLC controlled and have been fine-tuned based on system user input and design engineering parameters, include HAZOPS analysis and best practices followed from AES' SEMI-GAS line of gas cabinet equipment, and SEMI guidelines. Some of the safety features considered standard are exhausted cabinets, Z-purge electronics, hydrogen gas sensors, and safety interlocks all designed for safe and efficient operation.

The challenges of taking a heated, getter-style hydrogen purifier from idle to full process flow conditions have been met by a combination of tight process controls which allow for temperature and flow changes quickly and effectively, and the possibility of user adjustment through the HMI within the process parameters set forth at the factory.

Solutions for Complex Challenges Made Possible with the Right Partner

ARM Purification is committed to delivering solutions for the semiconductor industry's various challenges. ARM includes Ethernet as a standard offering, and users now have the opportunity to provide UHP H2 and real time monitoring for process hydrogen in variable flow rates for processes that require it in the most demanding of semiconductor processes. The purifier system can be tied in to SCADA or process control systems for full visibility, and comes standard with sub-micron particle filtration, and the availability of industry leading 1.5 nm filtration. If you have a hydrogen delivery application that could benefit from 9N hydrogen, but the flow variations in the process, or the high pressure loss of membrane purification technology have kept you from considering purification; ARM Purification has the product that excels under these delivery system constraints.

Learn more about gas purification that meets your unique requirements by visiting **armpurification.com**

To promote your products and services contact: **Shehzad Munshi**
T: +44 (0)1923 690 215 **E:** shehzad.munshi@angelbc.com

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GAS DELIVERY SYSTEMS

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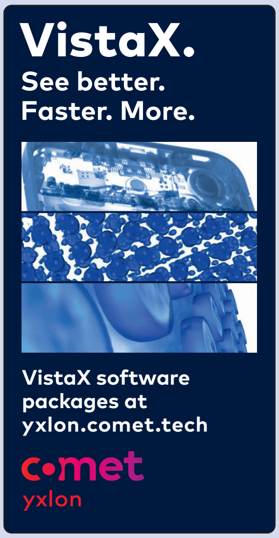
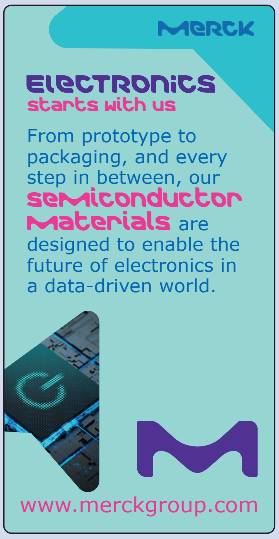


VACUUM EQUIPMENT

ETCH

GAS PURIFIERS

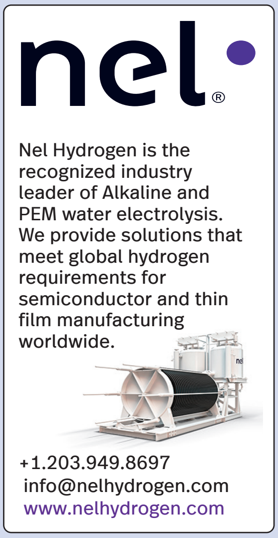
MATERIALS



VACUUM EQUIPMENT

FLOW MEASUREMENT

HYDROGEN GENERATORS



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