Reimagining Semiconductor MES

Advanced Fab Capabilities for Agility and Success

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New Semiconductor Imperatives

Keeping up with rising demand, product portfolio growth, complex products, processing mix, and new application requirements creates tremendous challenges for semiconductor makers. Companies must increase their pace of both learning and ramping up new products and processes.

Production operations are a pinch point. To handle new demands, companies must optimize further. Thus, it is imperative to reimagine the manufacturing execution system (MES) for semiconductor to meet today's needs.

MES must expand beyond work-in-process (WIP) and track and trace to become the data platform for production innovation, change, and efficiency. All types of facilities face this need, and modern MES can serve silicon, R&D, front-end fabs, back end, and even module production. While no longer isolated, front-end fabs face particular challenges and urgency due to their array of advanced capabilities.

Skyrocketing Demand Puts Pressure on Fabs

Opportunity is Everywhere

Unprecedented demand and industry growth rates are keeping semiconductor companies bustling. Projections are for continued rapid growth. And no surprise, since the smart connected world presents new opportunities for semiconductor manufacturers daily.

There are many markets beyond electronics & telecom, including automotive, medical, defense, avionics, industrial, consumer durables, and wearables. As a result of these market opportunities, companies face rapid growth in products, applications, customers, and revenues.[1]

Time for Rapid Change

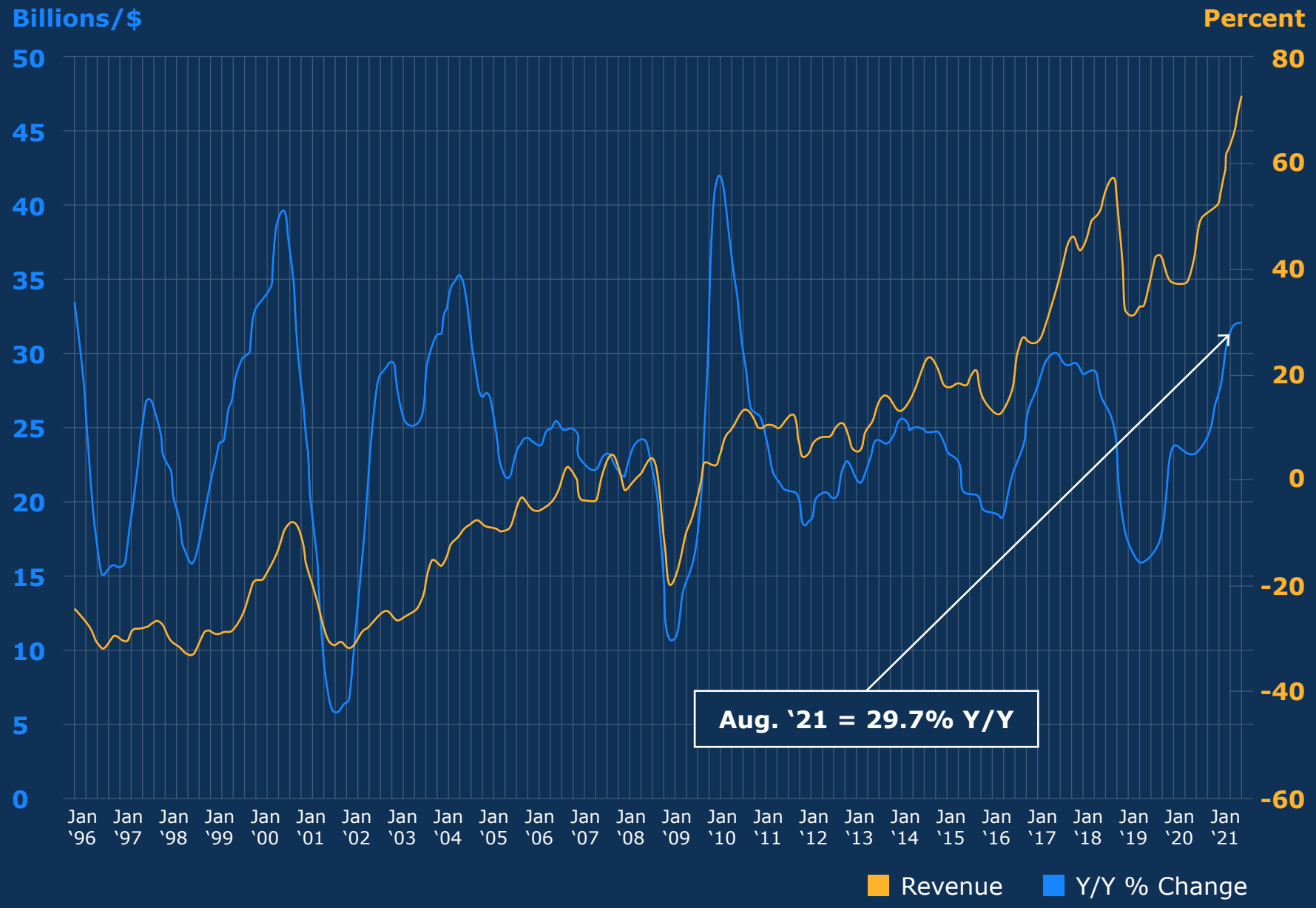
Semiconductor makers must focus, as always, on design wins. With new applications and customers, there can be significant work required to get approved as a vendor. After that, the pressure is on for both new processes and supplying customers' needs.

Pressure on Fabs

The need for speed, quality, cost, and innovation is not new for the industry. However, rapidly rising demand combined with many more products in the portfolio put fabs under greater pressure than ever. Many products require special treatment and advanced process capabilities. Turning data into information and insights for the fabs is a foundation for managing all of those products and advanced process capabilities efficiently and effectively.

"Everyone wants to know when their parts are going to be ready, but it's hard to say when it's on paper or scattered. A main selling point is to have one consolidated system and process flow that tells us when the parts will come out. If that date won't meet your contract deliverable, we can try to reprioritize."

Dr. Dana Wheeler, Deputy Director of Microfabrication Laboratory at HRL Labs



Source: "WSTS Semiconductor Market Forecast Fall 2021," World Semiconductor Trade Statistics, (c) 2021

Figure 1. Semiconductor industry revenues and percentage growth 1996-2021

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Innovation Issues

Product Evolution

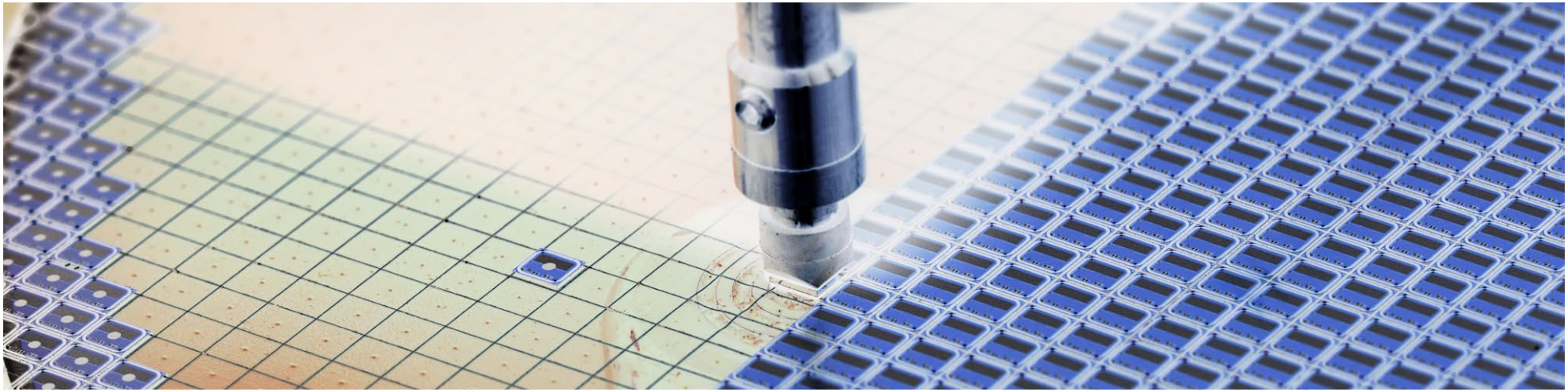
Over the past 10+ years, the diversity of products – in a portfolio and sometimes in a fab – has increased rapidly. Many semiconductor companies now offer newer and older technologies and line widths, simple and complex products. Stakes are high, as the smart products revolution also means many more applications carry high hazards. Semiconductor failures can cause human injury and death in smart cars, avionics, and medical devices. Many applications also need a small footprint and low power.

"We are 'More than Moore.' Our research focuses on what else we can do beyond getting smaller."

Dr. Frank Hochschulz, Project Manager, MES Implementation at Forschungsfabrik Mikroelektronik Deutschland (FMD)

Innovation is Pressing

The basic ways of innovation have not changed, but the need is pressing. In the fab, issues such as managing experiments and non-production wafers are prominent. Innovation must also occur with partners – research institutes, joint ventures, foundries, and customers. In short, ramping new products to full production at high yield, even with new materials and processing parameters, must be faster and more reliable than ever.



Meeting Demand

Broad Portfolios

Innovation and the breadth of product portfolios often mean a higher mix through the fabs, which poses a wide array of challenges. It clearly means more recipes, reticles, and mask sets to manage. Companies may also mix more experimental wafers and other non-production wafers during production runs, complicating product tracking and process sequences.

"We are a wafer fab for many different research institutes and external customers. So, we have many different flows – probably not quite 100, but many process flows per product line. Our challenge is to get all of those through the fab on a shared toolset in a timely manner. We often need different technologies on the same tool that don't play well together, and that causes scheduling conflicts."

Dr. Dana Wheeler, Deputy Director of Microfabrication Laboratory at HRL Labs

Demand for Capacity

With shortages worldwide, semiconductor fabs are operating at full capacity, and companies are adding capacity at a record rate. Yet, they have a solid backlog of demand. TSMC, for example, added capacity and still expects capacity to be tight.[2]

Capital utilization tends to dip with a higher mix, damaging throughput and operating margins. Part of this is ensuring equipment qualification; the operation must know the qualification state and what that qualification covers at every moment.

"Having invested millions in equipment, our challenge is to get ROI on it. We drive utilization and uptime of these machines. We also ensure, where we can, commonality in the projects and products we accept."

Dr. Frank van de Scheur, Head of MEMS and Micro Devices, Philips

Processing Challenges

Complex Processes

Complex products often require special treatment to achieve the needed characteristics and yields.

- Chamber-dependent recipes: Tools are complex, with many chambers that have varying capabilities for the process and materials. If one chamber is down, you need to know what you can and can't do on the tool at a given moment.
- Run-to-Run management: Creating the model for adapting a recipe and process parameters between runs is far more complex with mixed lots on the same equipment, which is increasingly common.
- Queue time constraints: Ideally, keeping track of every lot of products and ensuring none have excess dwell times is as automatic as possible.
- Equipment dedication: Ensuring products always go through the right dedicated equipment is common but harder to manage as more products are in the fab simultaneously.

Streamlining Flows

It is crucial to keep products moving quickly through the process correctly and confidently. With added process challenges and mix, it is increasingly challenging for people to play their roles effectively. For example, knowing which wafers to measure can be challenging without instructions for sampling by container.

"It can be so complicated. Let's say a product has ten layers. Let's say multiple tools can handle the etching in most of the layers. However, if we used a certain tool for etching in the first layer, this may limit the tools that that we can use in later layers not only for etching. But this restriction does not apply when another tool was used for etching in the first layer. So, what can be done at a given moment is not a trivial question."

Dr. Frank Hochschulz, Project Manager, MES Implementation at Forschungsfabrik Mikroelektronik Deutschland (FMD)

Progress Matters

Continuous Improvement

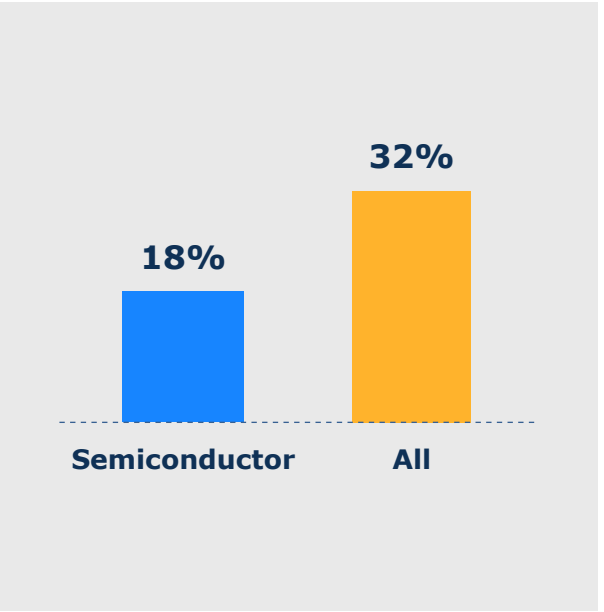
Most semiconductor companies do not feel they excel at continuous improvement.[3] This may be because of high standards, but it may also have to do with the challenges of accessing and contextualizing the massive quantities of data from semiconductor processes.

"Sometimes MEMS development takes several years. We want to keep industrialization lead time as short as possible to convert to manufacturing early. So, we need efficient, flexible, fast, and reliable processes. This includes managing experiments. In addition to design of experiments (DoE), MES must accommodate lots of short loops and split batches for where variants of the process options are running."

Dr. Frank van de Scheur, Head of MEMS and Micro Devices, Philips

Agility is Essential

Beyond improvement, companies must also be ready to change rapidly. The situation of supply chain disruption and uncertainty is not likely to change.[4] While many factors are at play, the need to quickly shift chip production from automotive to medical and back to automotive has illustrated the need for agility. In this way, all semiconductor companies need to operate more like research labs. Agility needs to permeate the entire organization more effectively.



Source: "The Manufacturing Data Challenge, © 2020, Tech-Clarity, Inc.

Figure 2. Portion of semiconductor vs. all respondents who rated themselves as excellent at continuous improvement

Quality Demands

Toward Zero Defects

As the impact of poor quality on customers' products and brands rises, expectations of quality rise as well. Product specifications and requirements are tighter than ever in many industry segments. Penalties for product failure can be high. To succeed, many semiconductor companies have a program to drive toward zero defects. Tech-Clarity research shows most semiconductor companies have higher expectations from customers for NPI time and quality.[5]

Prevent Contamination

Checking contamination of carriers, equipment, and measurement tools across classes that might travel between contamination zones is both essential and challenging. Tracking progressive contamination of carriers is another facet of the issue. Making contamination considerations an integral part of the material processing flow can prevent serious mistakes. Ideally, flows include materials, maintenance, and exception management for strong contamination prevention.

Boost Yield

Today, process and product complexity compound the age-old challenge of keeping yield high through the entire fab. Processes, equipment, and people in the fab all contribute to improving yields.

"To run a professional manufacturing organization, you must be in control with information about each of the process flows. Will the data you put into the system gain you access to get useful steering information to run the operation, such as availability, quality, throughput, and cycle times? We also needed to make the connection between MES and documentation and enterprise reporting systems."

Dr. Frank van de Scheur, Head of MEMS and Micro Devices, Philips

Empowering the Workforce

Retiring Experts

Nearly 40% of the workforce in the U.S. semiconductor industry is over 50.[6] More experienced operators, technicians, and engineers are the people who know how to work around challenges in the process. Information technology (IT) staff such as MES Administrators who have coded the current systems and maintain them are also retiring. Often, they are experts in programming languages universities no longer teach. Companies must get these experts to share their knowledge before they depart.

Recruiting Challenges

All manufacturers face a skills shortage, but it is acute in the semiconductor industry because it is smaller and processes are more complex than most. For example, China reports needing 400,000 more semiconductor employees to meet its goals.[7] Even with amazing products and processes, younger recruits are finding easier paths than semiconductor manufacturing. If they join, they expect guidance and easy ways to learn, collaborate, and gain expertise. They do not want to use old, green-screen software systems.

Less Experienced Staff

The result is that fabs must run with staff with some experience who are not necessarily the experts in any given process. Leading companies are striving to enable experienced workers' best practice knowledge to live in the system's processes. So, guidance comes from integrated and modern software rather than calling on senior staff members. This approach enables even those with no experience to do it right the first time most of the time.

"We are a research organization, so we have many new and non-specialized people such as students and scientists in our clean rooms. We have to take into account that they are not already experienced with the technologies or the MES. Ideally, MES should provide benefits for them as well as tools for them to control, plan and document everything."

Dr. Frank Hochschulz, Project Manager, MES Implementation, FMD

IT Overwhelm

Data Explosion

Naturally the growth of product portfolio, mix, and complexity creates an explosion in data, and thus, in IT needs. For example, recipe management and master data management are exponentially more challenging. Companies also need the ability to analyze the data. Advanced analytics are a foundation for rapid learning as new materials, processes, and products come into the fab. Coherent data analysis also enables sharing learning across the portfolio of products, equipment, fabs, and materials.

"Without having that master data, you might be in a situation where you have a process tweak in a common process like photolithography, but you can't leverage common learning between products."

Dr. Dana Wheeler, Deputy Director of Microfabrication Laboratory at HRL Labs

Inadequate Applications

Many semiconductor companies use older MES with limited functionality. Typically, these companies have separate systems for work-in-process (WIP) and track and trace (MES), equipment integration, maintenance, scheduling, reporting, and analytics. Maintaining integration between all of those applications is a burden.

Staff Needs

New products require extreme amounts of data analytics. However, if the data is not readily available and already in context, this is very cumbersome and time-consuming. Companies using an older MES system typically need large teams of qualified and scarce IT people dedicated to developing and supporting them. In maintenance mode, they cannot easily support the analytics the business needs to thrive.

Streamlining Information Systems

Helping Manufacturing Data Flow

Thirty years ago, MES came into semiconductor fabs to enable data to flow more easily. With all of the new challenges, the need for data continuity has grown significantly beyond WIP tracking and basic operational guidance. Today's highly automated fabs need to apply Industry 4.0 concepts. These include horizontal and vertical integration of information flows and data in context to enable more autonomy for equipment and products to do what is needed seamlessly.[8] Today's MES can do that.

"A custom Excel- or Access-based system for MES may not be a database-driven structure with a separation between data and applications. The new MES delivers that separation for improved master data management."

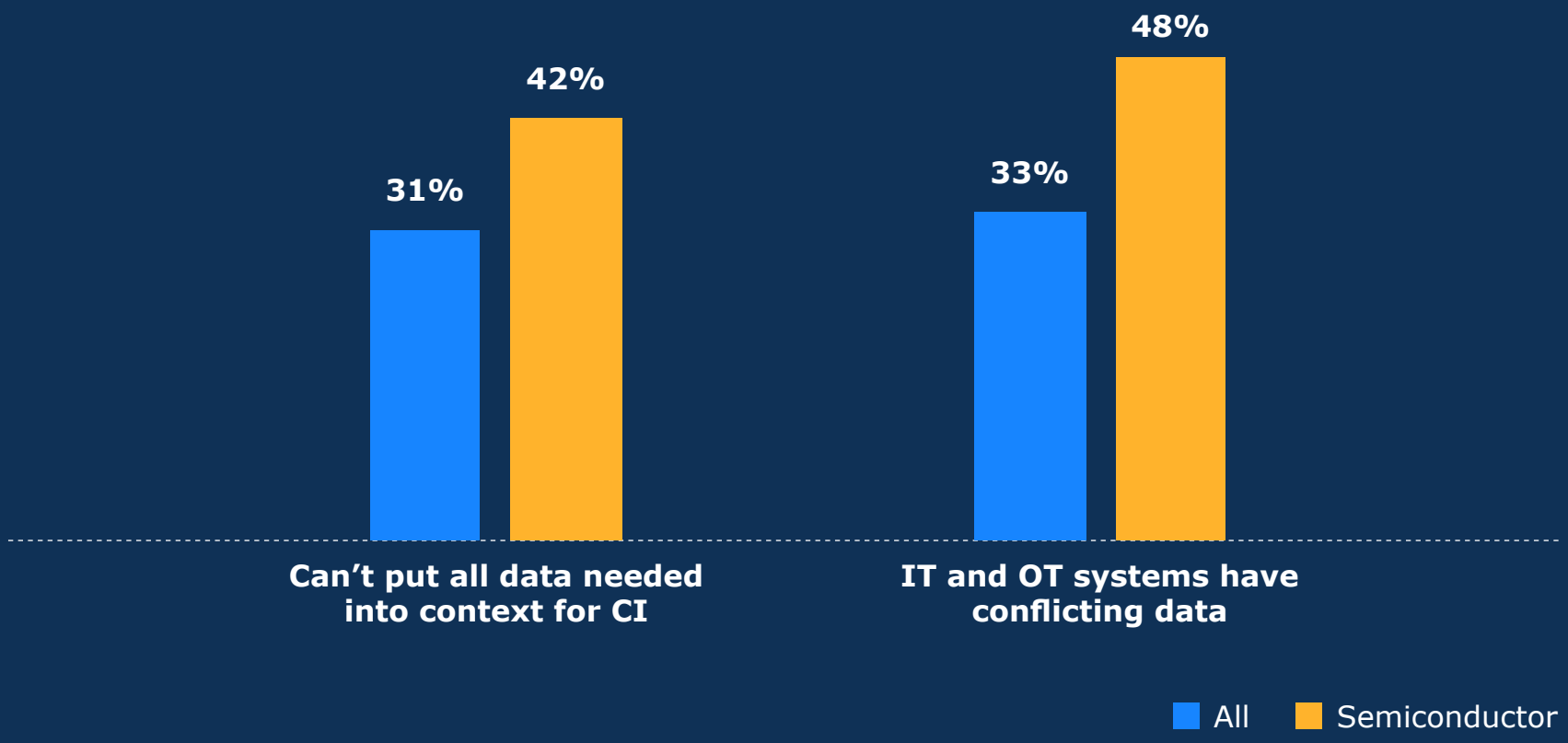
Dr. Frank Hochschulz, Project Manager, MES Implementation, FMD

Moving away from legacy

Replacing an older semiconductor MES can radically improve user experience and eliminate outdated IT languages, operating systems, and hardware platforms. It can expand functionality in a single system and keep pace with change. Combining MES and automation layers enables IT and equipment automation or operations technology (OT) data to become a single stream of information on all aspects of production.[9]

MES for Semiconductor Supply Chain

Ideally, a single MES platform can serve the entire processing lifecycle to support better traceability, as customers demand. Traditionally, MES for the fab was not suited to serve back-end assembly and test, and R&D and silicon needed different systems too. With today's configurable MES, it's possible to choose one supplier, one platform, to serve all of these. A single MES can streamline the IT landscape and improve data flows.



Source: “The Manufacturing Data Challenge: Lessons from Top Performers” Tech-Clarity, Inc., 2020

Figure 3: Challenges managing manufacturing data for continuous improvement: Semiconductors vs. other manufacturers

MES Reimagined

Modern MES Basics

If you have not reviewed MES products in over a decade, you may be in for a surprise. They are comprehensive but not monolithic. For agility in innovation and execution, they are also configurable and flexible. Some are suited to handling high-mix operations and include analytics as well as reporting. These systems can deliver new benefits in more unified data management across IT, OT, production, scheduling, maintenance, analytics, and advanced capabilities.[10]

"What is important in industrialization is the flexibility of changing things. We would like the flexibility to make changes to the flow during development. We expect our MES to minimize the burden of rigid administrative tasks for our engineers and operators."

Dr. Frank van de Scheur, Head of MEMS and Micro Devices, Philips

Manufacturing Data Management

To utilize the capacity and capabilities of the equipment and facilities, semiconductor companies need more advanced data management than most fabs have today. Beyond reporting, companies need good manufacturing data management. One aspect of that is master data management to enable faster system setup and ongoing benefits of data that can span applications and upgrades. Coherent data and analytics on that data also empower less experienced staff to make good decisions.

"We want to work faster, to serve more customer needs efficiently. One way to do that is to enable one scientist to process the lots of another scientist. The new MES ensures we can do that, by forcing us to use recipes for both production and development."

Dr. Frank Hochschulz, Project Manager, MES Implementation, FMD

Innovation	• Experiments management • Non-production wafer handling • Advanced analytics
Demand / Mix	• Recipe management • Reticles and masks • Equipment qualification • Configuration for agility
Process	• Chamber-dependent recipes • Run-to-run management (R2R) • Queue time constraints timers • Equipment Dedication • Sampling by container
Quality	• Send-ahead wafer management • Contamination prevention • Carrier contamination tracking • Continuous improvement • Yield management
Workforce	• Best practices • Sampling • Guidance • Modern UI • Decision support
IT	• Master data management • Equipment integration for IT/OT context • Sorter integration • Pre-integrated production, scheduling, maintenance • Modern OS, H/W, APSs

Figure 5. Modern MES for semiconductor functions, capabilities, and characteristics

Reimagine and Reinvest in MES

Expect More in Software

Over the past several years, fab processes have changed, and your Manufacturing IT must as well. Open your minds to reimagine what MES is and does. Evaluate MES against customer requirements and strategic business needs. As this paper describes, modern MES solutions go far beyond track and trace and WIP management to support advanced semiconductor processing capabilities.

Evaluate the Need

Most semiconductor fabs have a vast "hidden fab" where workarounds have become the norm. To understand that

- count how many systems you use to support fab operations today
- measure how much time, effort, and energy your team spends finding and consolidating data for day-to-day operations
- understand how much time the Manufacturing IT team spends maintaining and customizing the MES.

If you're dissatisfied with the answers, look for software that supports your fab's advanced capabilities.

Reinvest in MES

Push MES providers to get what you need. Some specifics you might need are in Figure 5. Beyond specifics, you need a smooth and coherent flow of data in the fab and into the enterprise. Speed of learning all you need to ramp up for NPI and continue improving yield and serving the market opportunities lies in that manufacturing data management. Investing is urgent – you can't be as resilient nor as profitable as you want without data that's in context and ready to use.

Acknowledgments

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About the Author

Julie Fraser joined Tech-Clarity in 2020 and has over 35 years of experience in the manufacturing software industry. She is an enthusiastic researcher, author, and speaker. She has a passion for manufacturing progress and performance gains through Industry 4.0 strategies and supporting software technology.

Julie is actively researching the impact of digital transformation and technology convergence in the manufacturing industries, with a focus on the plant floor and how manufacturing data can be used in conjunction with data from offices, labs, and the ecosystem.

About Tech-Clarity

Tech-Clarity is an independent research firm dedicated to making the business value of technology clear. We analyze how companies improve innovation, product development, design, engineering, manufacturing, and service performance through the use of digital transformation, best practices, software technology, industrial automation, and IT services.