Cahners
THE SEMICONDUCTOR INDUSTRY'S TECHNICAL AUTHORITY™
Vol. 24, No. 8
July 2001

semiconductor INTERNATIONAL

www.semiconductor.net

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Increase Productivity Through E-Manufacturing

At a Glance This survey-based article summarizes industry efforts for improving equipment productivity, and describes some components that comprise a complete equipment productivity solution. The way in which standards for equipment productivity are measured and improved is also discussed.

During the past decade, the semiconductor industry has undergone a dynamic transformation. It has shifted its focus on simply improving yield to a much broader effort of creating solutions for process equipment and factory productivity improvements with the goal of staying on the cost learning curve. Many companies and industry entities have put together approaches that appear to solve pieces of the puzzle independently. This is an exciting time in the industry: The value of integration finally outweighs the pain of integration and, at the same time, many seemingly independent solutions are actually converging on the same goal.

To reach a cohesive productivity solution, it is important to mention current dynamics impacting the industry. While individual equipment suppliers and industry players focus on niches in the productivity solution, two convergence trends are apparent. The first is a convergence of industry standards and guidelines for a streamlined, consolidated, industrywide approach. The second is a convergence of yield and productivity management. Concurrently, a third trend is also taking place: the advancement of information technology for industrial automation, specifically Web servers being used on the factory floor. This technology has opened a new realm of flexible server management, as it is not typically tied into the entire enterprise infrastructure. What these trends boil down to is that we are all finally speaking the same language and using the same terminology.

The challenge

For the most part, yield management is a well understood concept and, although it is still important, it offers limited cost-per-function-per-year savings in the future. And while the adoption of 300 mm wafers will net productivity gains, this alone will not enable the industry to meet its cost-per-function requirements in the future. As a result, managing overall equipment effectiveness (OEE) is increasingly important in the effort to improve factory productivity (Table 1).[1]

The industry is being challenged by a dramatic increase in IC applications. This generates pressure on integrated device manufacturers to shift their operations from high-volume, low-mix manufacturing to high-mix, low-volume manufacturing with short product lifecycles. Recently, traditional DRAM and MPU manufacturers have announced their first foundry operations. At the same time, foundries are emerging that are inherently subject to high-mix, low-volume manufacturing as a business model. This is leading to a fundamental change of how quality is managed. Mere product inspection does not meet

Table 1. Improving OEE: The Key to Future Cost Reductions

	Annual % Reduction in Cost/Function		
Factor	1980	1995	Future
Shrinking feature size	12%	12-14%	12-14%
OEE	3%	7-10%	9-15%
Larger wafer sizes	8%	4%	<2%
Yield improvements	5%	2%	<1%

(Source: International SEMATECH)

the demands of productivity and cycle times to assure profitability. Increasingly, manufacturers are turning to equipment productivity management to meet their profitability goals.

Also, IC makers are putting more pressure on suppliers to guarantee process equipment uptime at reduced costs. The guaranteed maintenance contracts in turn drive the need for rapid, precise diagnosis and repair of equipment to minimize service costs. These reduced costs can be reduced personnel, lower skilled labor requirements, or reduced spares inventory.

The opportunity

While new types of ICs are emerging as the basis for key technological developments, they are also driving the efficiency improvements of factories. From the equipment network to the factory network and the intranet, advanced yet flexible hardware and software information technology (IT) has emerged, dramatically reducing the cost-of-communications from basic equipment and subsystems to suppliers outside of the factory. Advanced IT provides the necessary information to improve equipment productivity and lower service costs at a dramatic pace.

At the IT equipment level, Ethernet technology is being used for high-speed reliable communications at low cost. Ethernet machine controllers are supplanting conventional field bus solutions for such demanding applications as motion control.[2] At the factory level, Ethernet and Web server technologies are becoming the automation standards for uses such as process control. Already advanced sensing technology uses high-speed Ethernet communications and Web server technology.[3]

Last, but not least, is the Internet. The industry is beginning to leverage this technology in the form of e-diagnostics. Solutions are being deployed to permit equipment vendors to remotely connect to process equipment, allowing vendors' technical support teams and applications engineers to remotely access data from process tools at customer sites over secure Internet connections.[4] Remote access enables rapid troubleshooting, reducing downtime and overall support costs.[5]

At every level, Ethernet and Web technology is creating IT standards for factory automation and control. The industry is moving quickly to adopt these solutions for improved IC manufacturing cost-per-function. Table 2 identifies several ITRS roadmap items that can be met by using IT.

Table 2: Improving IC Manufacturing Cost-Per-Function

Equipment Productivity Improvements	1999	2002	2005	2008	2011	2014
Technology node: Wafer size:	180 mm 200 mm	130 mm 300 mm	100 mm 300 mm	70 mm 300 mm	50 mm 300 mm	35 mm 450 mm
Bottleneck production equipment OEE (SEMI E79)	75%	87%	89%	91%	92%	92%
Average production equipment OEE (SEMI E79)	55%	65%	71%	78%	80%	82%
Relative maintenance and spares cost		<1˘ 200 mm	<98% of previous mode	<98% of previous mode	<98% of previous mode	<120% of previous mode
Overall factory non-product wafer usage (per wafer start)		<16% of production	<12% of production	<11% of production	<10% of production	<9% of production
Production equipment lead time (months from order to full throughput capability)	<9	<8	<7	<6	<5	<5
Production equipment installation, including hook-up and qualification cost as a % of capital cost	<6%	<0.95˘ of cost of previous node	<0.95˘ of cost of previous node	<0.95˘ of cost of previous node	<0.95˘ of cost of previous node	<0.95˘ of cost of previous node
Process equipment availability (SEMI E10)	>85%	>90%	>93%	>95%	>95%	>95%
Metrology equipment availability (SEMI E10)	>90%	>95%	>95%	>98%	>98%	>98%

☐ Solutions exist 🟨 Solutions being pursued 🟧 No known solutions

(Source: '99 ITRS)

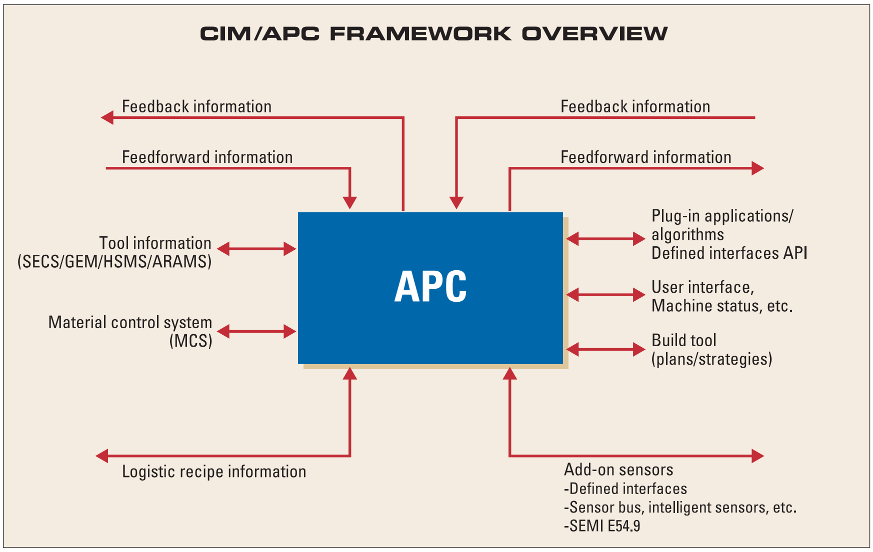
Web server technology

As the industry takes advantage of advanced IT, equipment productivity management is beginning to make great progress.[6] At the same time, a number of standards and guidelines are emerging to help us define the complete set of building blocks we need to rapidly deploy these technologies in semiconductor manufacturing.

Early attempts at improving equipment productivity fell under the advanced equipment control/advanced process control (AEC/APC) SEMATECH initiatives, resulting in numerous SEMI standards. Historically, AEC/APC has been divided into two applications. The first application, run-to-run control, provides feedforward or feedback control for tighter process control. The second application, fault detection and classification (FDC), manages equipment productivity by using equipment and process data to identify a process or equipment fault and the root cause of the failure. Figure 1 demonstrates the need for key data sources including sensors and equipment data for implementing AEC/APC. One result of these initiatives is the SEMI standard E54.9, Specification for Sensor/Actuator Network Communication for Modbus/TCP over TCP/IP.[7] This standard describes how sensors communicate over Ethernet.

Also, these Ethernet sensors use Web server technology for administration.[3] Using a simple Web browser, users can monitor the status of communications and sensor health, as well as configure the sensors for operation. Use of standard, readily available information technology makes it easy for a factory to deploy and maintain these products.[2]

This approach is being extended to process equipment.[10] The emergence of equipment servers is a result of the industry's desire to adopt modern IT for communications on the factory floor. Current process equipment uses industry-standard SECS/GEM peer-to-peer communication that may actually inhibit the industry from moving forward with process and equipment control. Peer-to-peer protocols prevent the user from easily accessing equipment data, which is a vital source for improving equipment productivity. Typically, this connection is dedicated to a host connection that ties the equipment to the manufacturing execution system (MES). Also, the SECS/GEM standard does not employ modern object-oriented interfaces like Java or Active X that allow for rapid development of software applications. By inserting an equipment server between the process equipment and the host connection, multiple users can concurrently access the process equipment through high-level object interfaces, thereby enabling APC and e-diagnostics equipment productivity schemes.



1. The implementation of AEC/APC requires key data sources including sensors and equipment data. (Source: SEMI Electronic Control Standards [ECS] Task Force 10/97)

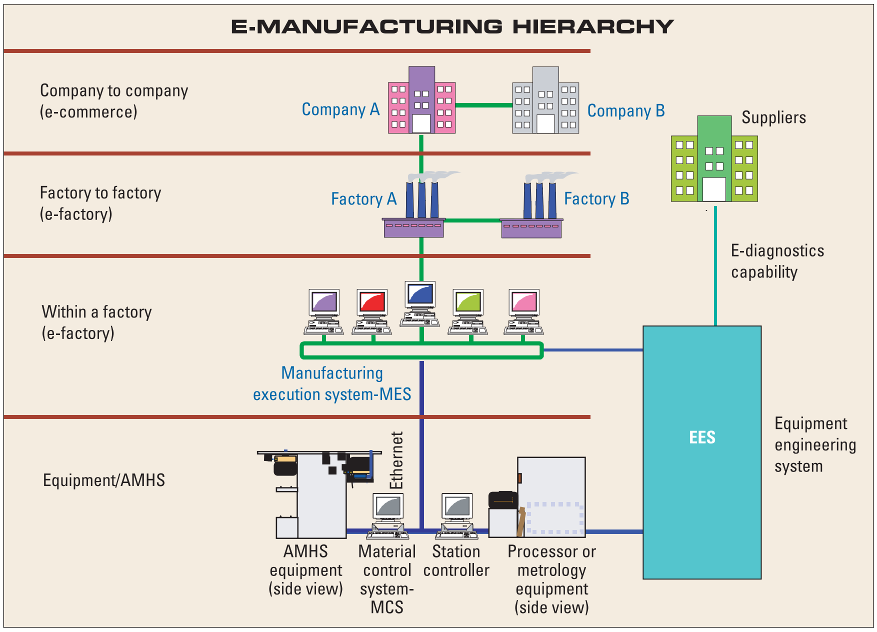
Converging standards, guidelines

While Web technology is emerging in the factory, semiconductor industry standards and guidelines are converging. Specifically, International SEMATECH and the Japan Electronics and Information Technology Association's (JEITA) equipment engineering system (EES) collaboration effort is focused on describing network connectivity for data sources, data acquisition and applications software in support of e-manufacturing. Figure 2 shows how EES fits into an e-manufacturing hierarchy. Figure 3 shows the various IT layers described in JEITA and International SEMATECH's EES scheme — where APC and e-diagnostics will converge.

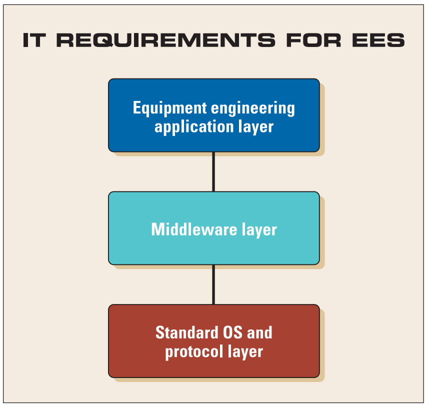
Conceptually, the low-level operating system defines standard communications for key data sources like process equipment and sensors. Functionally, this is similar to the way advanced sensors and equipment servers communicate today. The interface must provide high-level object-based communications that allow for concurrent communication by multiple users. In addition, these devices should be administered through a Web browser.

At the middleware layer, the requirements include standard methods for automated data collection and archiving from key data sources including process equipment, sensors and subsystems. Just as in other manufacturing industries, APC and e-diagnostic solutions in our industry will require high-speed parametric databases for archiving the large volumes of data from process equipment, sensors and subsystems. A data collection middleware component reduces the complexity of the task.

Today, data collection from SECS/GEM-compliant process equipment requires extensive knowledge of equip-



2. How an equipment engineering system (EES) fits into an e-manufacturing hierarchy. (Source: JEITA, International SEMATECH)



3. APC and e-diagnostics will converge in this EES scheme. (Source: JEITA, International SEMATECH)

ment SVID parameters to allow the user to gather the relevant information. Middleware allows users to configure data collection at a higher level of definition (e.g., chamber 1, rf forward power, etc.). And solutions exist now to provide these key functions.[9]

At the system level, applications take advantage of existing low-level operating systems and middleware to enable APC and e-diagnostic applications such as FDC to improve OEE, OEE to measure equipment productivity, and run-to-run control to improve process control. All of these applications communicate with process equipment, sensors and subsystems through an open object interface and talk to the real-time database through open object-based interfaces.

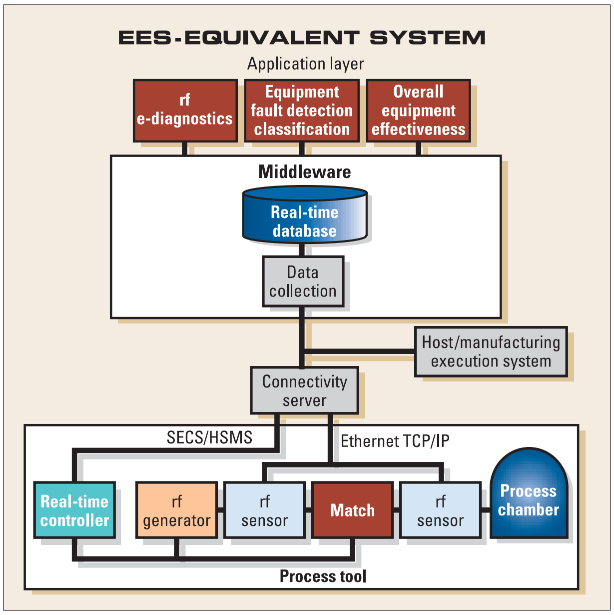
Finally, we have the current SEMATECH industry initiative for e-diagnostics. SEMATECH is producing a set of guidelines that provide the final piece of the puzzle for e-manufacturing. Much has been written about this initiative, with particular emphasis on OEE. The purpose of e-diagnostics is to enable remote, secure access to key data sources including process equipment, as well as process and yield databases to enable supply chain collaboration. This collaboration can reduce support costs and repair time. In addition, sharing information with the supply chain will drive continuous improvement and new product development.[8] While initial emphasis is on remote, secure communication to reduce MTTR, it is important to keep in mind that the guidelines include other capabilities like proactive monitoring and predictive/preventive maintenance, which are part of current APC FDC systems. One of the points of convergence for e-diagnostics and APC standards/guidelines is that the same information technologies serve both industry initiatives.

By surveying the various IT solutions available, it is possible to build a complete e-manufacturing solution. Figure 4 is an example of an EES-equivalent system being deployed today. Process equipment and rf sensors are connected through an equipment server to an Ethernet network. Data is gathered through a data collection manager and archived in a real-time database. Then applications for equipment productivity management analyze the data to determine the overall condition of the process equipment and the rf delivery system. Using this analysis, users can rapidly identify if the rf delivery system is impacting equipment condition. Having the subsystem monitor its own condition reduces equipment-failure diagnosis time.

Yield, equipment productivity

Running parallel with the convergence of industry standards and guidelines is the convergence of yield management and equipment productivity management. As the industry moves from a product-centric to an equipment-centric quality management approach, looking at the evolution of yield management helps us understand the evolution of equipment productivity management. Previously, early schemes relied on end-of-line electrical testing to manage product yields. As semiconductor manufacturing grew in complexity and technology matured, in-line inspection equipment was used to partition the problem of yield management. Operators used the equipment to manually measure defects and to assign types of defects to various process steps. At the same time, specifications for process equipment were developed including particles-per-wafer pass and defect density, to assure yield targets were met. Eventually, the complexity of the processes and advances in technology drove the industry to simplify defect categorization with automatic defect classification (ADC) software. In addition, software emerged for the automatic mining of yield management information to develop correlations between electrical testing and in-line measurement, helping to determine the root cause of yield-limiting events.

Equipment productivity management is evolving similarly. With the emphasis on equipment, initial efforts have focused on monitoring equipment states, including events and alarms. As

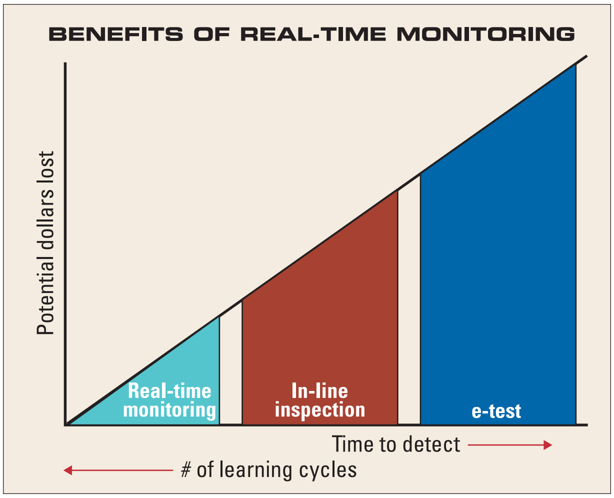


4. How an EES-equivalent system is deployed today.

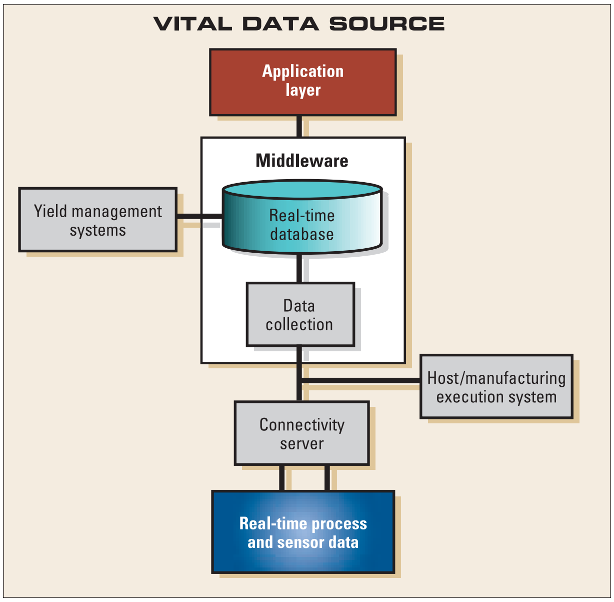
managing OEE becomes more complex, standards and guidelines have surfaced that require process equipment to report equipment states so that OEE can automatically be calculated by software applications.

In much the same way that defect density targets were set for yield management, OEE targets can now be set for various process steps. As these metrics are more widely used, additional information is needed to partition the problem further. In turn, this need is leading to data collection of specific process data and in situ sensors to further understand the condition of process equipment in real time. Eventually, understanding the causes of equipment degradation will require automation of equipment fault classification. One potential solution may involve the subsystems monitoring performance in real time and reporting on any degradation in performance.

Eventually, yield and productivity will converge. Figure 5 illustrates an added benefit to real-time equipment monitoring. As we move toward real-time equipment monitoring, the time to detect yield-limiting events and the dollars at risk will be greatly reduced. Real-time monitoring also increases the number of yield learning cycles, thereby reducing the time to ramp new processes. Figure 6 illustrates how the real-time process and sensor database provides a vital data source for both yield management and equipment productivity management systems.



5. Real-time equipment monitoring helps reduce the time to detect yield-limiting events, and increases the number of yield learning cycles.



6. Real-time process and sensor database provides a vital data source for yield management and equipment productivity management systems.

Conclusion

The emergence of advanced IT along with convergence of industry standards and guidelines, as well as the convergence of yield and equipment productivity management, makes this a fascinating time in the semiconductor industry. Diligent work by several industry suppliers and groups has resulted in fundamental developments that are changing the way we manage process equipment productivity. With increased benefits and improvements in overall information technology, the benefit-to-cost ratio has never been higher.

We must continue to pursue the standards, guidelines and definitions required to reduce the complexity of these solutions. Reassuringly, practical solutions and a well-understood roadmap to success do exist, and these must be used if we are to meet the roadmap goals for equipment productivity. •

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