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Full-on for the information age

FULL FACTORY AUTOMATION WILL BE CRITICAL IN MAINTAINING A COMPETITIVE, YET MATURING SEMICONDUCTOR MANUFACTURING PROCESS, PARTICULARLY IN THE COMMODITY CHIP BUSINESS. SUCH AUTOMATION IS EXPECTED TO MATERIALISE IN FOUR PHASES - 300MM MATERIAL HANDLING, COMMUNICATION INFRASTRUCTURES WITHIN FACTORIES AND INTERNET-ENABLED FACTORIES WITH A FULLY TRANSPARENT MANUFACTURING PROCESS. THE GOAL IS TO TRANSFORM FROM A TECHNOLOGY TO A MANUFACTURING BUSINESS WHILE PRESERVING PROFITABILITY. DR KARL MATHIA AND DR MARTIN AALUND OF PRI AUTOMATION PROVIDE A VIEW OF HOW ECONOMICS AND INFORMATION TECHNOLOGY ARE DRIVING THE DEVELOPMENT OF LIGHTS-OUT FABS WITH PLANNED AND 'HIDDEN' BENEFITS



Fig.4: PRI's TransFab aims to be a flexible automated material handling system (AMHS)

As the semiconductor manufacturing process is maturing, the industry faces shrinking profit margins. For all chip categories (logic, mixed-signal, processors, memory) significant market segments of the once highly profitable technology business will convert to manufacturing operations. More and more fabs will focus on high-volume production of mainstream commodity chips.

How can fabs maintain profitability in this highly competitive and sometimes hostile environment? One common answer is full factory automation, which is expected to become a crucial part of the semiconductor business equation. Although vision of a 'lights-out-fab' still needs 10 to 15 years to

fully materialise, some emerging trends and promising results, suggest how full factory automation will contribute to profitability.

We foresee four major phases of automation towards full fab automation:

Phase one: standards enable 300mm material handling

Phase two: communication infrastructures for data and control enables advanced scheduling and management of work-in-progress (WIP) within the fab

Phase three: internet-enabled factories communicating through e-diagnostics and e-business to the outside world

Phase four: integrated metrology enhances real-time advanced process control

Of course, transitions between these phases will be indistinct and difficult to point out. During the ongoing phase one, standards are enabling the transition from 200mm tool automation to 300mm material handling throughout the factory. Although several years behind schedule, this transition is advancing at a steady rate. Phase two, the implementation of communication infrastructures in factories, will enable flexible and fast scheduling of work-in-progress (WIP). During phase three, the fab-internal communication infrastructure will be internet-enabled, and e-business and e-diagnostics will make 'e-fabs' transparent to the outside world. Phase four will focus on the manufacturing process again, with

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integrated metrology as catalyst for tightened process windows and improved yields.

Economics dictates automation

While the industry seems to agree that the chip industry will venture into a high-technology landscape during the transitions from 200mm to 300mm and beyond, it is important to remember the driving force behind this transformation: economics. The high-tech fab of the future is not just about fancy technology - it is about fancy technology that generates profit in a maturing industry, similar to the events in the hard disk industry during the 1980s. Chip manufacturers face increased pressure to accelerate both yield curves and cost reductions. One solution seems to be full fab automation, where the two main challenges will be the escalating investments needed to build future 300mm fabs, and developing and implementing the technology required.

Escalating investments

Who will be able to afford to build fully automated 300mm factories, which could cost \$10bn by 2010, up from today's \$2bn price tag? If the industry continues along this path, many chip manufacturers will be forced to choose between chip design and chip manufacturing as their primary business. Thus we foresee three possible players with the capital available to build future fabs:

- large chip manufacturers with huge

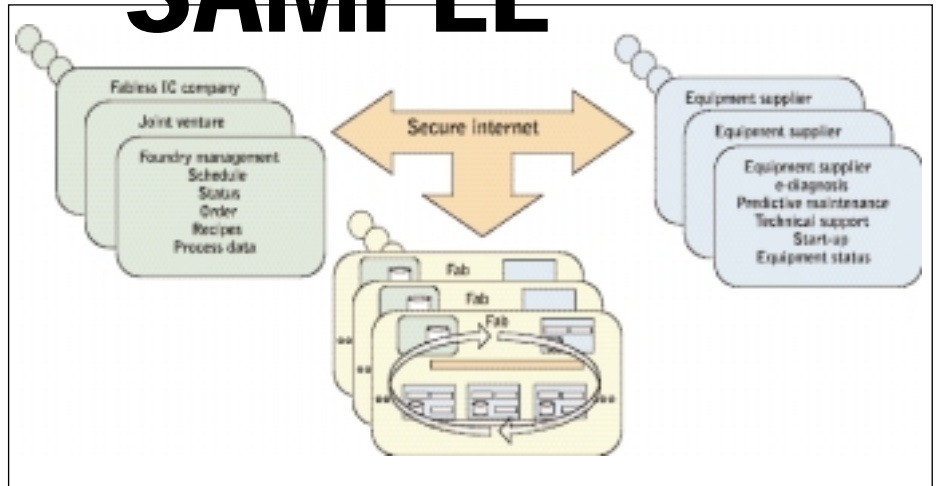


Fig.1: Infrastructure of global 'e-fab' industries

- markets for their mainstream products
- foundries
- joint ventures between manufacturers and/or foundries.

The first trend is obvious, while the second trend will be characterised by an increasing number of foundries as suppliers for fabless IC houses. Smaller IC houses will avoid the capital investment in new technologies and instead outsource manufacturing to foundries. As a result, the market share of foundries, which amounts for 15% of semiconductor production today, is expected

to increase to 50% within 15 years. Gigantic 'fab farms' on the Pacific Rim - and probably China - will share resources, overhead costs, and supporting facilities. For example, Motorola outsources 30% of its capacity needs to foundries, up from 9% in 1997. The third trend is the creation of joint ventures, where two or more partners will share the investments in new fabs and the subsequent manufacturing overhead. A recent example is AU PTE Ltd, Singapore, a 300mm factory jointly founded by US IC maker AMD and Taiwan's UMC foundry.

Lights out

'Full' factory automation, driven by economics, refers to automation in future lights-out fabs. Providing the manufacturing infrastructure, automation will play a crucial part in tomorrow's semiconductor business equation, reducing cost and improving yield. Cost will be reduced in terms of labour, work-in-progress (WIP), fab utilisation, and the separation of business and manufacturing processes. Yield will increase through more uniform quality within tighter process windows, achieving not only electrical yield (functionality) but also profitable target clock rates (speed).

Automation requirements are expected to include along with the four phases of automation given above:

- compliance with 300mm standards
- manufacturing flexibility
- compliance with available (and future) communications and security standards
- advanced process control, networked throughout the fab
- predictive Maintenance and remote diagnosis, start-up and support

Acronym	SEMI standard	Description
SECS-I	E-4: "SEMI Equipment Communication Standard"	Specifies how messages are sent between equipment and factory host
SECS-II	E-5	Describes message set that can be exchanged using SECS-I
HSMS	E-37: "High-Speed SECS Message Services"	Extends SECS-I standard to function over networks instead of RS-232
GEM	E-30: "Generic Equipment Model"	Describes the set messages from the SECS-II that should be used for communicating different types of information
OSS	Object Services Standard (1995) examples: E-40 (Process Job Management), E-41 (Exception Management), E-42 (Recipe Management), E-53 (Event Reporting), E-54 (Sensor/Actuator Network Standard), E-87 (Carrier Management), E-90 (Substrate Tracking), E-94 (Control Job Management), E-98 (Object Based Equipment Model)	Provides general terminology, conventions and notation for describing behaviour and data in terms of objects and object attributes

Table 1: Current SEMI communication standards

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The goal of 300mm wafer manufacturing is the well-known 30% cost reduction per die. Advanced scheduling software provides the flexible manufacturing process needed to reduce the work-in-progress (WIP), minimising the cost of goods in the factory overall. Besides unifying transport and scheduling, future manufacturing execution software (MES) systems also need to take into account lot location and tool availability to optimise transport and production in real-time. This is a formidable task, considering the large levels of WIP expected, the hundreds of process steps, and a highly re-entrant process flow. Optimising schedulers - like PRI's Leverage software - provide such features, including the responsiveness needed in an emerging marketplace, where foundries will simultaneously manufacture large varieties of chips for many customers.

E-business and integrated metrology

The synergy of full factory automation, e-business, and integrated metrology will not only enhance the current business model of fabs, it will transform fabs into 'e-fabs', creating profoundly different business models from today. Once a fab is internet-enabled - where the internal communication infrastructure is connected to the outside world - a variety of e-business applications will make the manufacturing process transparent to customers, suppliers, and partners, depending on the security and access authentication. This trend is ongoing in other industries and will be adopted by the semiconductor sector. Centralised and shared resources, almost independent of geographical location, will cut overhead and facility costs. Visibility of the manufacturing process will support trust and good supplier/customer relationships in the new business models. Former CEO of General Electric Jack Welch calls this the 'integrity of the process'. Customers will be able to view the status and location of a single wafer in the fab, modify orders and update forecasts in real-time. Equipment suppliers will be monitoring tools in real-time and diagnosing problems before they cause system crashes. PRI's StarCon controller is an example of an internet-enabled device, which can be accessed remotely via intranets or the internet. This feature will become standard for all levels of tool control during phase three (Figure 1). Internet-enabled fabs or foundries communicate through secure internet connections with customers (fabless IC companies), equipment suppliers, and centralised fab management.

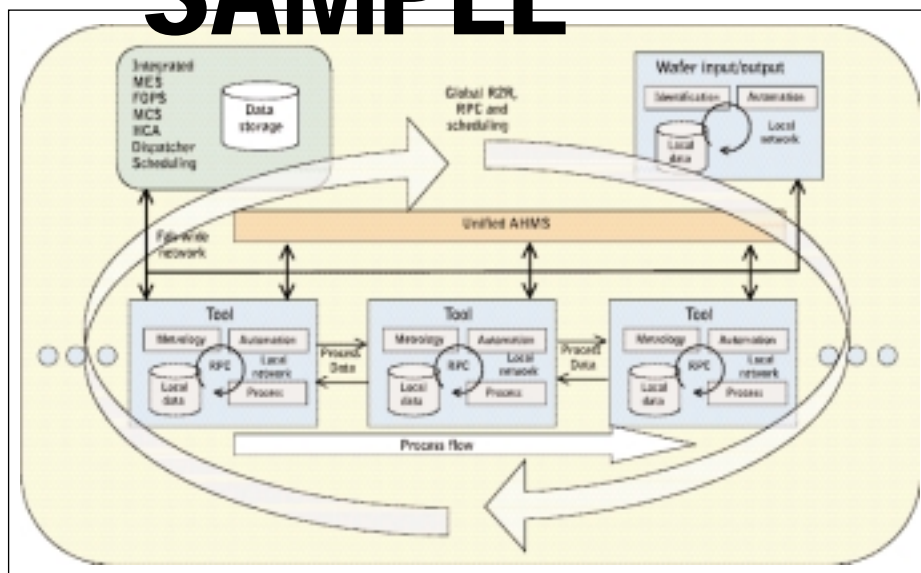


Fig.2: The 'lights-out' e-fab

The last step towards full factory automation - phase four - will integrate metrology into networked advanced process control (APC). Integrated metrology will enhance not only one tool, but a cascade of tools in a feedback/feedforward control system structure, communicating process parameter adjustments across the entire infrastructure. This enhanced process control system will reduce or even remove human subjectivity and decision making from the process and will therefore provide better process uniformity within tightened process windows, keeping up with critical yield improvement demands. Global fab visibility will allow the supplier to look at scheduled maintenance activities for all tools and efficiently schedule upgrades and maintenance with minimal impact on the manufacturing process. Suppliers will use real-time data for e-diagnostics and perform predictive maintenance only when required rather than preventive maintenance at regular intervals, whether it's needed or not. Improved process models and networked equipment will allow real-time APC (RPC) around multiple processes.

The hierarchical factory model (Figure 2) will make detailed information about a particular hierarchy level available worldwide to simplify day to day operations, as planned by the e-business model. Only relevant data needs to be displayed. Open network and computer architectures will allow 'write-once run-anywhere' applications to be developed, and object-based control and query software will be implemented at all factory levels. This

will allow queries and data mining through multiple levels to diagnose faults or to query a process status. Current and future communication and messaging standards will provide compliance across different hardware and operating systems.

Another cost and time saving feature is the reduction of wafer ID. Full fab automation will track FOUPs and each single wafer through the entire manufacturing process, from wafer scans at the input to the wafer output. Many scanners and wafer ID systems will be eliminated from integrated front end systems (IFEs), further improving throughput and reducing fab costs. For example, assuming 300 tools per fab and a \$1000 cost per scanner and wafer ID reader, savings of \$300,000 in capital equipment can be achieved. Figure 3 illustrates future tool features, including integrated metrology and automation interacting with real-time process control, centred around the tool's process and RPC with its internal and external communication infrastructure.

Present automation

The vast majority of 200mm and 300mm tools are already equipped with material handling systems. The automation process for 200mm wafer handling in tools may be considered completed, while standards currently enable the automation of 300mm tools. Equipment suppliers therefore focus on new technology to add features to these handling systems and to integrate interbay and intrabay automation

Current automated material handling

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systems (AHMS) - like PRI's TransFab - already provide unified transport throughout the fab for both reticles and wafers (Figure 4, page 19). These systems are the basis for the envisioned full factory automation 10-15 years from today. For example, a variety of wafer handling components, like robots and pre-aligners, already meet the handling needs of most of today's tools. Developments are targeting better performance and new features of these components - such as refining motion control, enhancing user software and improving wafer cleanliness via edge gripping. Many robot/automation controllers come with graphical user interfaces and allow for automatic teach and re-teach of relevant tool positions.

Integrated front-end systems (IFEs) integrate intrabay with interbay AMHS. These mini-environments remove wafers from FOUPs and transfer them to process or metrology tools. For this purpose IFEs will also be equipped with an enhanced communication infrastructure and with environmental controls for airflow, air pressure, and to prevent static build-up, while maintaining a sub Class 1 environment. IFEs are also used as scanner and sorters. Combined with sealed FOUPs IFEs have already allowed fabs to tolerate Class 100 cleanliness, which may increase to Class 1000 with full factory automation.

Standards have been a key enabler of 300mm wafer automation and its integration with AHMS and MES systems. A challenge towards full fab automation is the creation of

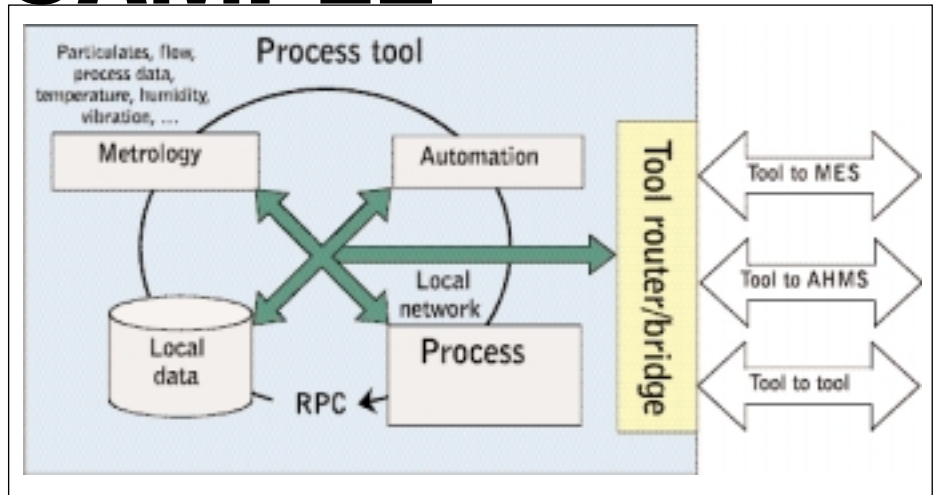


Fig.3: Fully automated process tool

new standards, in particular for communication. This need is driven by the emerging communication between tools, factories, and the outside world. It appears that the current SECS/GEM and 300mm communication standards will not suffice to provide adequate security, protocols, and channel capacity. The "SECS Gap Analysis for e-Diagnostics" from SEMI's Diagnostic Data Acquisition Task Force states:

"The SECS communication technologies and the GEM control and communication state models, as defined today, do not meet the data collection and access control requirements of e-Diagnostics."

The reasons stated include:

- SECS-I does not support multiple independent clients
- Neither HSMS, SECS-1 nor SEC-II provide for authenticating protocols, making it impossible to guarantee single point of control (security issues)
- The GEM communication state and control models do not include the identity or role concept to distinguish between clients, thus preventing user level access control

A requirement will be to allow for simultaneous data access from multiple users while maintaining a single point of control. Local gateways will have to be developed so that intra-tool data collection will not radiate unnecessarily to all points of the fab. Most of these communication issues are new to the semiconductor industry. Standards and solutions can be transferred from other industries.

Other challenges include constantly rescheduling the factory for priority hot lots and select recipes for exceptional wafers. The automation system will not only transport material, it must also start and stop processes, sort and track wafers, lots and FOUPs, probably with 'zero-footprint' wafer storage available. Emerging applications like ultra-thin wafers will add to the difficulties to be resolved, and plug-and-play systems will be expected from equipment suppliers in order to reduce integration and start-up costs.

Automation Phase	Economical Motivation	Enabling Technology	'Hidden' Benefits
#1: Standards, 300mm automation	300mm factory automation, reducing labour cost	Tool automation, AMHS	Cost savings due to elimination of redundant hardware for material verification
#2: Communication infrastructure	Advanced automation, material handling	Predictive maintenance	Flexibility, reduced WIP, scheduling and fab utilisation
#3: Internet-enabled factories	Increased fab utilisation	e-diagnostics, e-business	Trust in process, customer relations, overhead and facilities cost, travel, etc.
#4: RPC, integrated metrology	Electrical yield, more uniform labour quality, cost	Advanced process models, relation between processes	Tool reliability, profitable 'speed yield'

Table 2: Benefits of factory automation

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