A Framework for Semiconductor Manufacturing

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Introduction

Manufacturers confront a common problem of integrating a factory with components from multiple vendors. Ever changing market demands compound integration problems by requiring flexibility in manufacturing. The Automated Manufacturing Research Facility (AMRF) at the National Bureau of Standards (NBS) is investigating integration and flexibility issues in computer integrated manufacturing of machined parts. Researchers at the AMRF have successfully integrated a wide variety of "off-the-shelf" components into a single consolidated factory while maintaining a high degree of flexibility in processing [8] [11].

The AMRF factory is based on data driven intelligent controllers within a distributed hierarchical architecture. This paper outlines the framework of the AMRF factory and discusses each of the components as they apply to semiconductor manufacturing control.

Problem

Semiconductor manufacturers share many problems of integration and data collection with other manufacturing disciplines as seen in [1] [2] [6] [7]. The processes involved in semiconductor fabrication, however, are much more complex and the data collection needs are much higher than a typical processes in a machine shop [12] [13]. Similarities between semiconductor and machining domains occur at higher levels of abstraction, where manufacturing activities consist of 'manufacture batch', 'inspect lot', and 'package lot'. These abstract activities apply to a number of manufacturing domains. Hence, domain independent activities are limited to low level processes and controllers.

As geometries decrease, the amount of process data required for control will increase dramatically. Management of this data will become an increasing problem that could easily overwhelm the unprepared. The control environment must be able to handle ever increasing amounts of process data without an unnecessary burden on processing.

Automation and flexibility in the semiconductor manufacturing process is required to reduce misprocessing, improve equipment utilization, improve time-to-market for new products, and meet the demands of an ever changing market [4]. Continued growth of application specific integrated circuits (ASIC) will require most factories to be flexible job shops instead of fixed flow shops. Automation and flexibility cannot destabilize the process or decrease process yields. In fact, processes must be more stable and yields improved while achieving the needed automation and flexibility.

Another problem common to manufacturers involves non-standard equipment level protocols for data transfer and communications. The Manufacturing Automation Protocol (MAP) was developed for general manufacturing domains while the Semiconductor Equipment

Communications Standard (SECS) was developed for semiconductor manufacturing. The issue of higher-level control communications between cells/workstations has not been standardized and remains an important integration problem [3].

AMRF Overview

A major goal of the AMRF project has been the establishment of a testbed small batch manufacturing system at the NBS Gaithersburg, Maryland site. The testbed, which became operational in 1983, is designed to be used by government, industry, and academic researchers for the development, testing, and evaluation of potential interface standards for manufacturing systems. To ensure that as many critical system integration issues as possible could be addressed, component modules were chosen from many different vendors. Therefore, the NBS testbed differs from virtually all other flexible manufacturing systems in the variety of "off-the-shelf" components that have been integrated into a single coordinated operation.

The industrial machinery of the AMRF occupies a 5000 square foot area of the NBS machine shop. The factory systems that are located on the floor of the AMRF include: two machining centers and a turning center, a coordinate measuring machine, six robot manipulators, a vision system, two wire-guided vehicles, storage and retrieval systems, tray roller tables, tool setting stations, vacuuming and other cleaning equipment, part fixturing, and robot gripper systems. Integration test runs of the AMRF have demonstrated the successful automated production of small batches of machined parts. Integration concepts used are described in [9].

Hierarchical Control

A multi-layer hierarchical control framework is used to decompose manufacturing activities (Figure 1). Each level in the hierarchy decomposes an activity into simpler

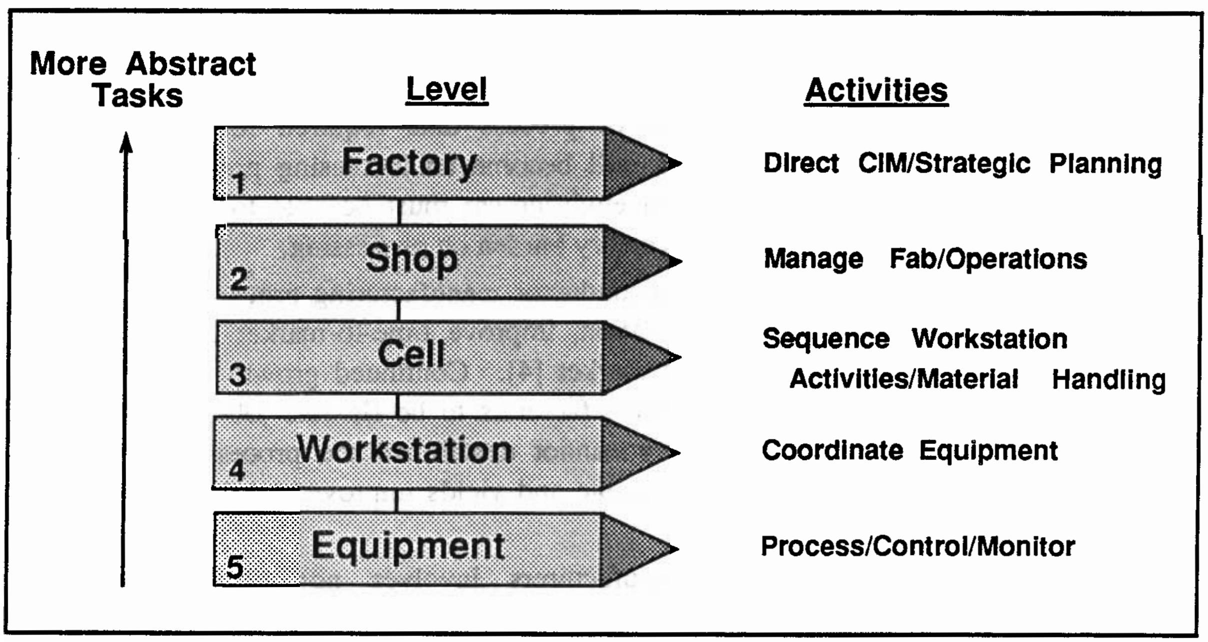

Figure 1 : Levels of Factory Hierarchy

activities which are sent to the next lower level controller. Decomposition continues until the equipment level activities are specified. Command and status messages are passed between levels in the hierarchy to control processing. The exact number of levels and the associated names are somewhat arbitrary; the key issue is the multi-level hierarchical control environment.

Since terminology is often defined differently by different people, the hierarchical levels of the AMRF and the associated terms will be explained. The equipment controller (level 5) directs processing of a single piece of equipment and consists of downloading and executing recipes for process equipment, numeric control (NC) code for robots, and real-time data collection. Workstations (level 4) coordinate activities between associated robots and process equipment for a particular process such as photolithography, chemical vapor deposition (CVD), ion implant, etch, or material handling between workstations. A workstation is a collection of equipment which is integrated to perform a series of related operations to produce the desired change of state in the wafer. An example of a lithography workstation would include cleaning, depositing resist, exposing, developing, and inspecting. An assembly workstation would consist of scribing (diamond, saw, or laser), attaching, bonding, sealing, testing, and inspecting. Cell controller (level 3) activities include sequencing of tasks and material handling between workstations. The Cell controls all processing from wafer preparation to assembly and test. Different semiconductor fabrication lines would be under the direction of different shop controllers (level 2). Shop level controllers are concerned with managing a particular fab, resource management, inventory control, and similar activities. For example, there might be a MOS product line and a Bipolar product line. The factory level is responsible for overall planning and corporate level tasks.

Within the hierarchy, the complex equipment processes typical of semiconductor manufacturing are derived from simpler, more abstract activities. For example, figure 2 shows the hierarchical decomposition of process steps for a lithography process. The equipment level tasks are completely specified by recipes that are executed directly on the equipment. Details of the equipment protocol are hidden at the lowest level. Similarly, details of the workstation configuration are hidden from higher levels. Each level may

Shop	Cell	Workstation	Equipment
Process Batch	Process Lot	Position Cassette	recipe014
Process Order	Inspect Lot	Pull Wafer	recipe316
	Mask	Fixture Wafer	recipe200
		Spin	...
		Apply Resist	
		Unfixture Wafer	
		Mount	
		Bake	
		Unmount	

Figure 2: Example of Decomposition of Tasks in Hierarchy

operate independently from higher levels to provide local control and fault tolerance.

Data collection and data processing are handled at the lowest level possible in order to prevent the enormous amount of data generated from overwhelming the entire control system. Each level in the hierarchy has access to a centralized database. Database transactions are passed directly to the database, i.e. they are not passed up the hierarchy. Process control data can be analyzed by the appropriate controller without affecting other controllers.

Programmable Control

Programmable control within the hierarchy is achieved by using process plans - a process specification language developed to formalize process task execution sequencing (Figure 3). Process plans specify the sequencing of activities for each level of the control hierarchy [10]. Individual tasks are called *work elements*. Work elements are used to specify processing activities in increasing detail. Resource utilization information is used to provide data for scheduling.

A process plan exchange format has been used successfully in the AMRF for several years. It basically embeds a Project Evaluation and Review Technique (PERT) or critical path network (CPN) structure. A new process plan format is under development which provides for multiple alternative process tasks and concurrent execution of process tasks. In addition to process task specification, process resource utilization information is embedded in the process plan to allow scheduling and management of resources. Controllers at each level in the hierarchy use the process plans to direct activities. Flexibility is gained since new process sequences require only a new process plan, rather than the development on low level programs.

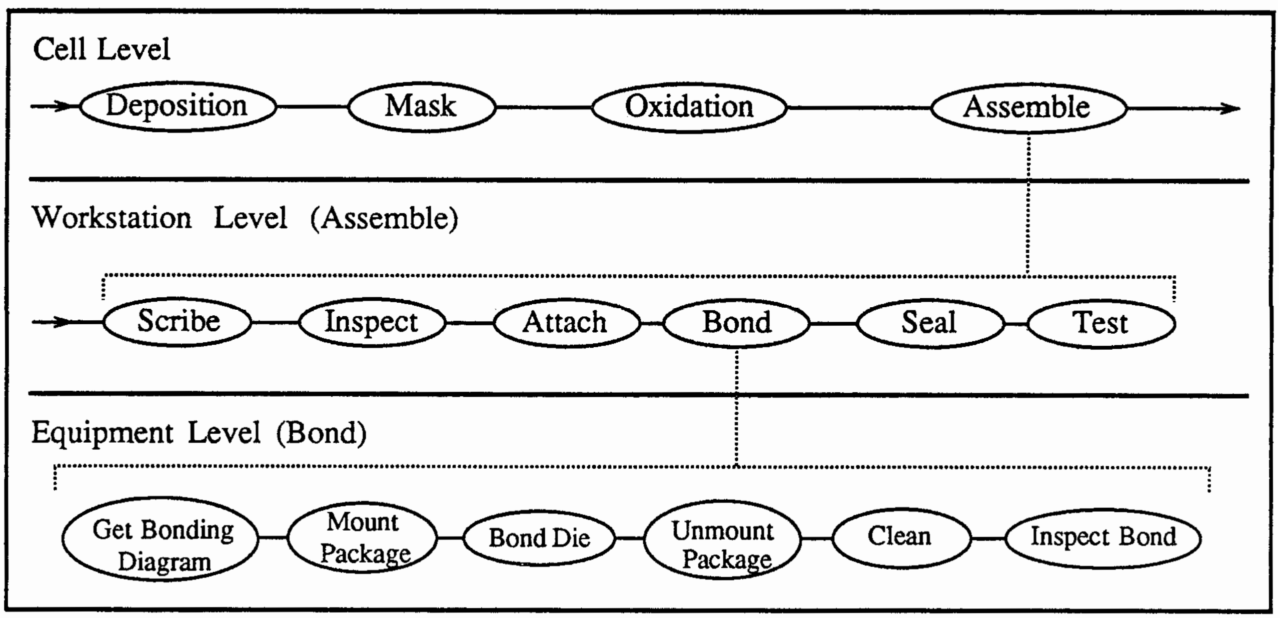

Figure 3: Example of Process Plans

Generic Controller Model

With the proliferation of factory controllers comes increased maintenance and development costs. For this reason, a generic controller architecture has been developed to minimize redundant code and reduce maintenance costs. The AMRF controllers are based on a generic controller architecture which uses AMRF internally standard process plan format and communications protocols [5]. The controllers use the process plan to coordinate processing at each level in the hierarchy and to manage resources and schedule tasks. Expert systems can be easily incorporated into the generic architecture to provide localized intelligence for process control. The generic architecture also reduces development and maintenance costs of controllers by reusing large amounts of software.

Distributed Computing

The AMRF distributed computing environment supports fault tolerance and localized intelligence. Each controller may be distributed on a separate computer, and controllers themselves may be distributed among multiple computers. AMRF standard communications interfaces, process plan formats, and data transfer protocols allow for distributed control of the integrated factory. Network transparent user interfaces provide monitoring of controllers throughout the factory. This allows an operator to remotely monitor any number of controllers from a central location.

Data collection and processing in the distributed environment reduces the amount of data which needs to be transmitted between controllers. The data processing burden is pushed down onto the lowest possible controller. Higher level controllers are not concerned with the data.

Distributed computing provides computer power at the appropriate location. Expert systems, scheduling, data processing, and other computer intensive tasks can be distributed between computers to maintain real-time responses. Distributed systems provide an increased degree of fault tolerance by eliminating the single point of failure. Furthermore, with the advent of inexpensive computers, allows incremental implementation of automation without incurring the large expense of most large monolithic computers.

Conclusions

The semiconductor industry confronts many of the manufacturing problems already resolved at the AMRF. Three key concepts of flexible manufacturing have been presented: multi-level hierarchical control, data driven manufacturing, and distributed computing environments. The concepts presented address the problems of integration and flexibility within an automated manufacturing environment required by semiconductor manufacturers.

References

[1] W. A. Bösenberg, "A 'Structured' Approach to CAM", *Semiconductor International*, June 1987, pp. 62-68

[2] P. Burggraaf, "Semiconductor Factory Automation: Current Theories", *Semiconductor International*, Oct. 1985, pp. 88-97

[3] P. Burggraaf, "CAM Software-Part 1: Choices and Capabilities", *Semiconductor International*, June 1987, pp. 56-61

[4] P. Burggraaf, "CAM Software-Part 2: Implementation and Expectations", *Semiconductor International*, July 1987, pp. 63-65

[5] B. A. Catron and B. H. Thomas, "Generic Manufacturing Controllers", To be presented at *3rd IEEE International Symposium on Intelligent Control*, Arlington, VA, August 1988

[6] R. C. Dehmel and G. H. Parker, "Future VLSI Manufacturing Environment", *Solid State Technology*, May 1987, pp. 115-121

[7] R. A. Green, "Automating a Semiconductor Manufacturing Facility", *Proc. Robotics and Expert Systems Conf.*, pp. 65-68, Pittsburgh, PA 1987

[8] R. J. Hocken and P. Nanzetta, "Research in Automated Manufacturing at NBS", *Manufacturing Engineering*, Vol. 91, No. 4, October 1983, pp. 68-69

[9] C. R. McLean, "Interface Concepts for Plug-Compatible Production Management Systems", *International Journal of Computers in Industry*, (9), pp. 307-318, 1987

[10] C. R. McLean and P. F. Brown, "Process Planning in the AMRF", *CIM Technology, August 1987, pp. 23-26*

[11] J. A. Simpson, R. J. Hocken, and J. S. Albus "The Automated Manufacturing Research Facility of the National Bureau of Standards", *Journal of Manufacturing Systems*, Vol. 1, 1982, pp. 17-31

[12] H. A. Watts, "CAM: Lot Tracking and More", *Semiconductor International,* July 1987, pp. 66-68

[13] P. Van Zant, Microchip Fabrication, Semiconductor Services, San Jose, CA. 1984

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