OPPORTUNITIES in COMPUTER INTEGRATED MANUFACTURING

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Abstract

Improved *computer-integrated manufacturing* (CIM) systems are needed to enable competitive production of high-technology products. The increasing complexity of processes and products, the growing need to manufacture different products in a single (costly) factory, and the rapid rate of change in product and process technologies all are trends that create a demand for better utilization of information.

The problems of VLSI production typify those in high technology manufacturing. There is a strong need to unify data used for product and process design; equipment, process and facility control; quality assurance and testing; and production scheduling and control. Improved capability for modeling, simulation, and direct control of production processes and equipment is needed. Guaranteed real-time performance is often required. Major advances in the human to computer interface are sought to facilitate effective use of complex integrated information systems.

Introduction

Present and future manufacturing of VLSI components and other complex products requires coordination of hierarchies of thousands of different materials, process steps, machines, and human operations. [1], [2] The quality and productivity of the manufacturing enterprise requires dynamic management of vast amounts of information. Thus, computers have become a critical tool in high technology manufacturing. Unfortunately, the current status of CIM technology resembles the situation of CAD for microelectronics in the mid-1970s. The turn-key information systems now used for microelectronics manufacturing support only a fraction of the total task. They are difficult to integrate with other computer-based systems for product design, equipment monitoring and control, and in-process and final test. A number of important problems in CIM can be attacked with the tools and know-how of the design automation community.

Information management

Strong efforts are needed to unify the data needed to support the entire manufacturing enterprise. Much greater use should be made of structured data, e.g. formal database system techniques. A data model that supports late binding of queries is highly desirable because it simplifies development of new uses for common data. Historically, the relational data model has been the dominant choice supporting late binding of queries. Manufacturing data generally has less inherent hierarchy than VLSI mask design data, so considerations of retrieval speed are less likely to force adoption of specialized data structures for management of manufacturing data. When data with hierarchal structure is used, a modern CAD database offers attractive features. [3] Future general-purpose database management systems will support version control, user-defined data types, and active mechanisms such as triggers and alerters. [4] These features will be very useful for CIM. Interchanges among the inevitably different databases for design, manufacturing, and test should be facilitated through extensions of the *Electronic Design Interchange Format* (EDIF). [5]

Today, information on manufacturing processes often is represented in haphazard manner. It is common to find multiple unstructured representations *(views)* of the same item with no systematic means to assure mutual consistency. Consider a recipe for VLSI wafer fabrication process, typically consisting of hundreds of small operations. The following representations are frequently employed:

- formal process specification document
- informal engineering descriptions to aid visualization
- equipment control commands to execute the process
- input file for a process simulation program
- specification for in-process tests and final test

The problem of maintaining the consistency of these multiple representations is being addressed through development of a formal process definition language. Appropriate software interpreters will be used to create the varying representations needed for different uses. Mutual consistency of the different views will be achieved by permitting changes only in the formal high-level definition. The situation here has many similarities with the problems being attacked by the design community through development of the *VHSIC Hardware Description Language* (VHDL). [6] Of course, ultimately there must be a linkage between the product and process definitions.

Modeling and simulation

Numerical simulators for devices, circuits, and systems are well-established tools in the design community. Simulation is much less used in VLSI manufacturing. Improved simulation techniques could sharply reduce the amount of costly trial-and-error experimental effort now commonly employed in debugging and refining manufacturing processes. Needed in this area is stepped-up activity in development of adequate models for production processes and equipment. Statistical models are necessary in many cases. Additional work on equipment and process modeling and characterization will likely lead to improved fundamental understanding, better capability for closed-loop process control, and improved equipment design.

Expert systems applications

There is a strong effort now to expand the science base underlying manufacturing technology. Clearly every effort must be made to continually expand the fundamental understanding of manufacturing processes and equipment. As noted above, more effort on modeling and simulation of manufacturing processes is likely to aid in the development of improved understanding. Improved monitoring of process execution and process results will add to the empirical knowledge base. Heuristic aids should never be considered as a replacement for the above items.

It's a common observation that the best practitioners of any complex technology or process often obtain better results than could be obtained based upon fundamental understanding or empirical data alone. Many investigators are attempting to capture the heuristic rules-of-thumb that are thought to be the basis of outstanding human performance and make them readily available via expert systems technology. Manufacturing is clearly an arena in which heuristic reasoning is useful. Creative efforts to encode heuristic knowledge may well lead to valuable aids to support manufacturing. Potential application areas include selection of process parameters within a range of possibilities, diagnosis of equipment or process problems, monitoring of operations including appropriate data compression, and training systems for new operators. An example of an exploratory system is reported elsewhere. [7]

User interface

Manufacturing information systems mostly fail to exploit modern user interface techniques. Today's systems at best provide ASCII terminals for text communications with users. Menu-driven and/or command driven interfaces are used, but the standard of user friendliness far below the best examples in personal computer software. Modern VLSI production facilities should operate without paper, in interests both of microscopic cleanliness and of accurate, timely data management. Most semiconductor manufacturers prefer the versatility of human operators to fully automated systems for material handling, in large part because automation cannot keep up with frequent changes in equipment and processes.

Progress has been slow in implementing direct connections between high-level management systems and the real-time microcomputer controllers embedded in most semiconductor manufacturing equipment. Human operators are frequently required to load or adjust production equipment in response to computer-generated instructions. They may be called upon to enter data based upon direct visual inspection or upon measurements with analytical instruments. Keyboards are less satisfactory than in office environments. Human operators in production clean rooms wear gloves, gowns, and caps and should spend only a small fraction of their time directly involved in computer use. There is substantial background noise, most importantly from the rushing nearly 'white' noise of laminar flow air curtains. All these circumstances call for imaginative use of modern input/output techniques including icons, interactive graphics, pointing devices, voice or sound output, and (if possible) voice input.

Conclusion

Developments from the design automation community have improved human productivity in integrated circuit design manyfold over the past 15 years. In the semiconductor manufacturing arena, new VLSI production lines now cost $100 to $200 million. Present turn-key information systems fail to meet important needs in VLSI manufacturing. If improved computer information systems can be shown to improve the productivity of such facilities by just a few percent, they would justify multimillion dollar investments. Some of the major problem areas in computer integrated manufacturing can be addressed with the tools and capabilities of the design automation profession.

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