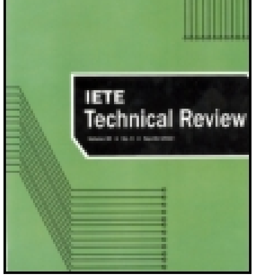

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Role of Automation and Robotics in Semiconductor Industry

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This paper presents the current trends in automation and robotics in the semiconductor industry. The semiconductor manufacturer, in order to survive in this industry, has to maintain a state-of-the-art facility and for that he has to invest in automation. The reasons for automation are myriad; principal among them are yield and throughput enhancement, improved process control, faster turnaround time and development of a sophisticated test bed for research activities. The paper dwells extensively on reasons, benefits and objectives of automation.

Automation systems comprise of a distributed computer architecture; mechanization systems; process control systems and logistics systems. Implementation of automation systems should be carried out in a phased manner so as to achieve bottoms up integration. Both system buildup and implementation strategies are discussed in detail.

In the Robotics section development of robots for clean room application is discussed. Starting from repeatable jobs robots have acquired advanced capabilities such as vision and intelligence. In this light the anatomical parts of clean room robots and special requirements for their construction are discussed. The futuristic trends such as guided vehicles are also surveyed.

Towards the end case studies for automation as applied to wafer fab and device assembly have been presented along with the blueprint for automation at SCL.

AUTOMATION

SEMICONDUCTOR business is unique in the sense that as the design and technology upgrade, the price of the product comes down. In order to stay in the industry it is imperative to go in for an automation system. This is also necessary because of the newly emerging trends in the semiconductor industry which force the manufacturers to remain competitive and maintain the state-of-the-art facility [1]. These factors are (*i*) Increasing level of integration, (*ii*) Decreasing minimum feature size, (*iii*) Increasing process complexity, (*iv*) Thrust for quality, (*v*) Process control and yield optimization, and (*v*) Ease of operation.

In this context we would like to quote from 1984 SEMICON West Show's inaugral address of George Moore, SEMI Director, who said "As the industry moves towards higher densities of large scale and high speed circuits,...automating the fab line will result in tighter processing controls and higher yield" [2]. Yield is of paramount importance in this industry. Yield and automation go hand in hand. Thus automation is the only hope for the future.

Reasons for automation

The overriding reasons to automate fab lines and these reasons are true worldwide are to increase productivity and lower the cost. Productivity can be increased by using larger wafers, making denser circuits on them and having lower contamination and defect levels.

Larger wafers are not only difficult to handle manually without damage, but because of their higher densities are more prone to the impact of contamination; for both reasons machines are better suited to handle them.

The main reasons for automation are listed as under [3-5]

(*i*) Complex processes and high density circuits require process consistency and repeatability. Only computer controlled machines can provide such features.

(*ii*) Improvement in throughput are achieved by automated systems as they never change shifts and thus significantly increase equipment utilization time.

(*iii*) Automated systems provide faster turn around time for fabrication of VLSI devices, as automated product queuing systems minimize the idle time during which wafers sit and collect defects.

(*iv*) The investigation of relevant material, process, device and circuit limits in sub-micron VLSI research requires unprecedented degrees of process control and monitoring. A flexible automated system offers the promise of fulfilling these needs. This gives an impetus to research and development activities by providing a "cutting edge", sophisticated and flexible test bed.

(*v*) Automated systems promote paperless fab concept, thus eliminating papers used in fab for maintaining records, logs, batch cards etc. This would lead to ultraclean work environment of class 1, thus resulting in enhancement of yield.

Considering all these benefits it would be impossible to survive in the business without investing in automation systems. In this regard there is an interesting quip by Doug Lockie, President of Strategic Technologies, Inc, who said, "As far as automation in the Semiconductor Industry, it looks like the Cobbler's children are finally getting shoes!", meaning that the technology being developed by semiconductor manufacturers is being used to aid the device manufacturing itself [2].

Defining automation

Automation in semiconductor industry can be defined as an integrated system of a number of subsystems which include mechanized movement system, information system, logistics system, process control system and people/procedures. All are linked via a host computer system which forms its backbone and base. Figure 1 shows the pegging order of such a sub system [6,7].

The backbone

The fundamental backbone of an automation system should comprise of a set of software applications which can consist of programs to control mechanical, electrical and process parameters and sequencing of events. Thus the software programs consist of management information systems, expert systems, schedulers and work-in-progress tracking programs. The host computer generally is

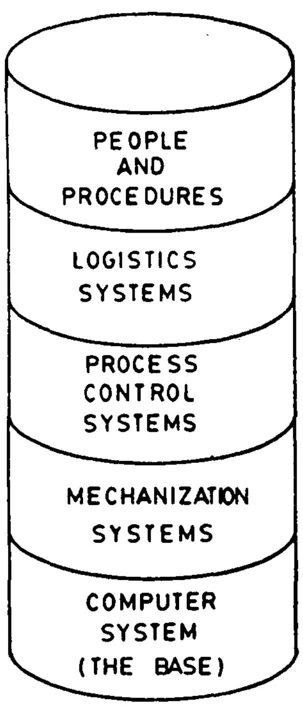

Fig 1 Totem-pole representation of the elements of a semiconduc-

super mini (*eg*, VAX, Prime) system wherein all the software packages would reside and run. All individual equipments and work area terminals would be networked to this host using SECS I/II protocols or through Local Area Hosts (LAH).

Mechanization systems

Such systems comprise of cassette-to-cassette transfer systems, robotic components and in some cases automatic guided vehicles. Details of such system would be covered in the section on robotics and while discussing case studies.

Process control systems

One aspect of such systems is automatic process control through which preprogrammed process parameters are fed to the machines and subsequently monitored by the computer system. Another aspect is closed loop automatic control which detects a process drift and generates a warning for the human operator. The third aspect is statistical process control which compiles statistical data on various process parameters resulting in repeatability and consistancy in the process leading to higher yield.

Logistics system

The key to successful logistic system will be a master plan for controlling product routing and priority assignment. Such system comprises of a scheduler program which allocates tasks to be completed during a shift and assigns jobs to equipment and operators. Some automation experts are of opinion that WIP tracking system are a subset of logistic systems. These systems are particularly helpful in knowing, "What is where?".

People and procedures

This could comprise of an expert system which would guide the work force in day to day operating procedures and to help in conducting yield improvement and process tuning experiments even in the absence of area experts. The knowledge base for such a system can be formulated from the experience of the experts in various areas of manufacturing [9].

Objectives of automation

Once the decision to automate has been made, criteria must be established for evaluating equipment and ability of suppliers to provide appropriate support. The most critical factor in making such a choice is that the system selected must be evolutionary and adaptable, thus lending itself to phased growth.

While evolving an automation system strategy the following questions need to be answered [7].

. How much adaptability must be built in?

. How flexible is the plan to evolve to full automation?

In view of the above questions an analysis of proposed automation system should be carried out in the following format.

Eliminating product handling by operators

For efficiency and minimization of defects it is imperative to eliminate direct handling of product by operators. Research on this has led to significant improvement in cassette-to-cassette handling system and a standard called 'SMIF' has been developed for mechanical interface [8].

Appropriate identification methodology

Many technologies have been developed for the identification of wafers and cassettes. These include laser wafer titler and bar code system for cassettes.

Computer control of process equipments

Some degree of computer control is essential; the user should determine just how much. Some key areas to look for are, Automatic parameter setup, Multiple levels of equipment control, Conformity with SEMI SECS standards, and Automatic process data collection.

Flexibility of CIM/CAM architecture

The basic architecture of the overall CAM system should be carefully considered. An expert opinion is that a distributed architecture is most suitable as it works in a fail safe mode, has multiple control and is modular so that a bottoms up integration can be achieved.

Protection from contamination

The equipments used for automation should be such that they do not generate particulate contamination resulting in killer defects on the product.

Adequate equipment reliability

Suppliers should guarantee a certain minimum level of reliability on equipment. Generally it is demanded that overall system up time should be greater than 95%, which means component reliability should be better than 99%.

Acceptable throughput levels

The automation strategy should be implemented in such a way that the overall throughput should necessarily increase.

Usability

Usability is a broad term denoting the ability to make a successfull transition to automation. Following key

. Operator training

. Configurability for line integration

. Automatic setup and recalibration

. Supplier assistance.

Implementation strategies

Since a large number of components are involved in any automation system it is essential to evolve a strategy and a sequence for putting the system together. In context of semiconductor automation, a five phase buildup strategy is recommended [7].

Phase 1: *Establishment of the CAM system base*

CAM system base should be established first since it forces the user to define basic system architecture for the total automated line. The computer system is obviously a natural place to start because it can be put into place even before the automated process machines. Once this back bone is set; an easy bottoms up growth is possible by using Local Area Host (LAH) distributed throughout the floor.

Phase 2: *Mechanization of process machine systems*

With computer system ready to serve as the binding force individual machines can be automated one by one. This is implemented through cassette feed systems, standard interfaces, automatic process sequence control, automatic recipe set up and monitoring.

Phase 3: *Adding CAM application at LAH*

At this juncture central computer becomes involved, linking local process stations (*eg*, Implanters, Steppers) for the purpose of process data monitoring, equipment status monitoring, failure prediction, diagnostics etc.

Phase 4: *Sectorize into critical area groups*

In this phase fully automated discrete tools can be organized into integrated sectors such as lithography, diffusion, etching etc. Within each sector the previous three phases are fully implemented.

Phase 5: *Robotics based logistic system*

At this point user can take a giant leap forward and add clean room robots and mechanized cassette carrier systems which carry products between the sectors.

Overview of some leading CAM systems

There are some commercially available CAM subsystems which cater to automation in various areas of Semiconductor Industry. Notable among them are described briefly [6].

supplier of diffusion furnaces, has become involved in CAM market through FACS, a furnace analysis and control system. This was later enhanced to WICS, a wafer inventory control system. Through this management information reports could be generated providing information on wafer lots in process.

(*ii*) BBN Software Corporation has developed a software package titled RS-1 which is a data management and analysis package that provides data entry and retrieval, two and three dimensional graphics, curve fitting, statistical analysis and analytical modelling.

(*iii*) Consilium Associates Inc have developed a CAM system called COMETS (Comprehensive Online Manufacturing and Engineering and Tracing System). It is composed of eleven modules dedicated to various specific functions such as WIP tracking, capacity planning and scheduling, engineering and managerial data analysis.

(*iv*) Fairchild have developed an Archival Computer Aided Yield Tracking and Evaluation System (ACYTE). This is a real time process control system providing feedback and monitoring for all the key elements in the wafer fabrication, assembly and testing cycles.

(*v*) I P Sharp and Associates have developed probably the most advanced LAH system called PROMIS (PROcess Management Information System). This has several facilities to create and display user defined descriptive information or diagrams about any object in the wafer fab.

ROBOTICS

The new crop of intelligent clean room robots owes its existence to the developments in the semiconductor industry. Faster, more powerful microprocessors and cheaper memory have made the robots more versatile and economically much more feasible to IC manufacturers. In this section we propose to look at what robots do in clean rooms today, and how they are designed to accomplish these tasks [10-12].

Historical perspective

Compared to application of robots in other traditional industries such as steel making and automobile manufacture the development of robotic application in semiconductor manufacturing has been rather slow. Several reasons could be assigned for this slow pace; notable among them are as follows [10].

. Until recently, robots were no cleaner than human operators, thus they were not acceptable for clean

. The established robot manufacturers did not pursue the clean robot with same zeal as they spread the use of their machines in more traditional applications.

. Wafer fabrication process is not as operator intensive as some other areas in semiconductor manufacturing. These areas, particularly device assembly were subcontracted by the western manufacturers to cheap labor oriented Asian countries.

. Moreover, the faltering economy had put the semiconductor industry in a capital investment crunch and revolutionary equipment like robots were the major casuality.

Developmental stages of clean room robots

The evolution of clean room robots into a workable tool in semiconductor manufacturing process is a good news for more than just the robot vendors. Robotics also represents a potentially brave new technology for the producers of semiconductor production equipment to exploit. In the clean rooms it would mean that human operators would have less repetitive, higher skilled jobs. Also it would present a new challenge to the engineers and technicians who will have to adapt to the ways of "ROBOT" [10].

Figure 2 shows the developmental stages of the robot for semiconductor industry. As the robots become more advanced their capabilities and sphere of application increases. Fundamental differences exist between familiar industrial robots and their clean room counterparts. Significant design changes in the robot, such as sealed joints are required to eliminate particulate contamination. The robot's outer cover must be constructed with a material that resists flaking and shedding of particulates.

Robots in their simplest form are machines which perform the basic function of repeatability. This is the ability to return again and again, to previously taught point or points, as such application of these robots was limited to pick-and-place tasks. Earliest use of these robots was to put in and off-load boats of wafers from diffusion and CVD furnaces.

A step further in evolution was imparting accuracy in addition to repeatability. This is the ability to locate a point on its own by being given a mathematical description of that point in its software programming. Such robots can handle tasks of transferring wafers from boats to cassettes or putting cassettes into various machines.

More sophisticated robots have intelligence added to repeatability and accuracy. Such robots offer vision, tactile sense and decision making abilities. Vision, imple-

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