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A FACILITIES VIEW OF THE LOW-VOLUME, HIGH PRODUCT MIX FAB*

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A FACILITIES VIEW OF THE LOW-VOLUME, HIGH PRODUCT MIX AUTOMATED FAB

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Automation has been widely recognized as the next major step in semiconductor manufacturing. ~~and~~ Numerous manufacturers around the world have been spending large sums of money to develop integrated automation systems for microelectronic chip production. Automation is a manufacturing tool that can be used in many facilities both new and existing, but the power and effectiveness of any automation project can be enhanced by a facility that is designed to be automated.

Experience at Sandia National Labs

This paper is heavily based on experiences gained in the design, construction, and startup of Sandia's newest cleanroom known as the Microelectronics Development Laboratory (MDL). The MDL is a Class 1 facility of individual process bays organized around a central hallway. Chase areas separate the process bays, and whenever possible, equipment is mounted through the walls to allow maintenance to be done in the less clean chase areas.

Sandia's varied interests in microelectronics result in a large number of different types of devices or products, and most of these devices involve total runs of just a few lots. Many of the decisions made at Sandia were influenced by the low volume, high product mix nature of this facility, and may or may not be applicable to a commercial microelectronic production facility.

Sandia has elected to use a distributed hierarchical architecture as shown in Figure 1. This means a centralized cluster of computers to handle facility wide decisions and data storage, bay or cell controllers distributed along a network from the central cluster, and equipment distributed among the cell controllers using serial data links between equipment and controller. The distributed architecture was chosen for its robustness, efficiency in data transfer, and simplicity of interfaces at the equipment level.

Another decision involved the choice of AGV's (Automated Guided Vehicles) over fixed robots, tracks, or some combination of these choices. The development work that occurs in Sandia's cleanroom translates into a significant need for flexibility, and an AGV based system seemed to provide the best solution for this requirement because of the AGV's ability to rapidly reconfigure for changes in equipment or routing requirements.

Choices such as overall system architecture and material delivery systems can have a major influence on the structure of the automation system. Most of these choices will lead to a usable system, but the selection of an approach should be made as early as possible.

Organization

The physical location of process equipment is critical in any facility, but automation places additional restraints and requirements on the already complex task of equipment location. In an ideal world, the processes and equipment set would be known at the time of facility design, which would allow the facility to the "built around" a specific set of equipment. In reality, the technology is advancing at such a rate that facilities are often designed with only a general idea of the equipment set that will eventually be in them.

A high product mix facility aggravates this problem by introducing multiple, often dissimilar, flows of product through the fab. The layout that streamlines a particular product flow may not work as well for other products that are produced.

The solution to this is to organize the facility by functional cells. The functional cell or bay should consist of the equipment needed to perform the "functional blocks" that go together to form a process flow. These blocks are a group of steps that are always performed together regardless of the overall process details, and fortunately, these functional blocks are easily spotted in most process flows. An example would be a group of furnaces, a bench to do the cleans for the processes in the furnaces, and inspection equipment to handle the films produced by those furnaces.

In other words, Sandia has decided to put Ten lbs of process in a 5 lbs Bay.

Sandia has chosen to use physical bays to accomplish the functional blocking task. Individual bays contain the equipment needed to accomplish the tasks required of their functional block. Diffusion processes are handled by two different cells, and each has a wet process bench, a bank of vertical diffusion furnaces, and film thickness inspection equipment. In a similar fashion, the photolithographic cells contain coat tracks, steppers, develop tracks, inspection equipment, and strippers for rework. Additional cells, and their associated equipment, exist to handle ion implant, wet etch, dry etch, chemical vapor deposition, and metal films.

There are occasional gaps between theory and practice, however, and problems arise when expensive equipment is required in two different cells. Few companies are willing to purchase multiple copies of equipment unless the capacity of that equipment is being exceeded. Sandia has solved this problem in a couple of different ways. The first is a resource allocation scheme between the cell control computers that allows equipment to be logically part of one cell at one time, and another cell at another time. In the diffusion area, this allows each cell to have one type of inspection equipment physically located in the bay, and still have access to another type of equipment located in the other bay. A second solution is to isolate the unique equipment in its own functional cell even if it is physically located within another cell or bay. The more sophisticated inspection equipment has been handled in this fashion at Sandia since it is generally used on small samples or test wafers and is not considered part of the primary product flow.

Layout of the functional cells within a facility should locate the automated cells in one group with the manual cells (inspection, research, etc.) in another group. This will prevent the material handling system from having to pass through or by a cell full of humans. This will cut your overall cycle times by reducing your transit time, and will improve the safety of the the overall facility.

Sandia has organized its facility such that the majority of the planned automated cells are located at the west end of the facility. The significant exception is the metal films cell that is located at the far east end of the facility because of the large chase requirements of the metal equipment. This has resulted in a long run down the central hallway before and after each metal process and means that transport to and from metal takes up to four times the time needed for other transport steps. This also means that the AGV dispatched to pick-up or deliver material to that cell is unavailable for other uses. The problems associated with this single distant bay make a strong argument for keeping the automated cells in a compact physical layout.

After the equipment that belongs to a functional cell is identified, the layout of that equipment within the cell can also be optimized to some degree. The direction of that optimization may vary depending on the goals of the facility, but a cell might be optimized to reduce overall transport time, transit time between certain types of equipment, or another variable that helps meet the facility goals.

Equipment location within the cell is always influenced to some degree by requirements for power, gases, exhaust, etc., and automated equipment has the additional restraint of communications cabling to consider. At Sandia, the choice of a local cell controller for the bay and SECS-I links between equipment and cell controller meant that the length of cable runs between the equipment and controller had to be considered along with a method of passing cables through the clean room walls. A different architecture for automation might require different types of links to the equipment and imply different problems, but the issue of communications cabling remains a factor in any automated facility.

Space Requirements

Despite the tremendous advances in robotics over the past years, no robot comes close to humans in terms of efficient use of space. A robot that could move material with the flexibility of a human in the same space as a human would be a tremendous boon. Since such a machine does not exist yet, trade-offs must be made to acquire the amazing accuracy and repeatability offered by robotic handling systems, and one of these trade-offs is in the area of required space.

Robotic handling systems are so desirable, that most processing equipment is now being offered with some form of automated handling that extracts wafers from the carrier cassette, transports the wafer through the process, and returns the wafer to the cassette. Most equipment of this type takes some amount of extra space for the handling mechanism, although this may be almost nothing to a great deal of extra space. Much of the space required by automation is therefore included in the space taken up by process equipment, but additional space is required by the systems that transport and store material.

The choice of a material transport system has a significant effect on the space planning effort, and should be selected as early as possible. Sandia has chosen an Automated Guided Vehicle (AGV) based system for its flexibility in loading process equipment and its ability to be rapidly reconfigured. AGV's of various types, fixed robots, rail mounted robots, tracks, monorails, and other systems are all viable transport systems for the clean room, so no attempt to compare the various types of material handling schemes will be made here. Different fabs have different needs, and the final plan may include many different types of material transport systems.

In any case, plenty of space must be provided for the material transport system. The activity envelopes of the various robots within the automated fab should be planned carefully to prevent overlaps that will cause collision problems. This planning should also cover topics such as human/robot interaction, the additional space occupied by a machine that is under maintenance, and the possible conflicts between the inter-equipment transport mechanism and the equipment's own transport mechanisms.

Automated storage of work in process, much like automated equipment, requires more space than conventional storage schemes.

Sizing the storage capabilities of the fab is an important aspect of space planning. A low volume facility such as Sandia's will not require much additional floor space for inventory storage, but a higher volume facility may require considerable space be allocated for material stores. This means larger storage buffers assigned to each cell, plus the addition of intermediate or zone storage buffers to accommodate the overall inventory. Sandia's facility has been sized to handle 75 to 100 lots in process at any one time, so an I/O buffer for 12 cassettes in each cell is adequate for the needs of that facility.

Finally, a quick mention of an area that is often overlooked in planning, and that is space for terminals or workstation consoles within the bay. The area should include enough space for people to interact comfortably with these devices.

Failures and Repairs

Although improvements are being made constantly, processing equipment, including the material transport system, does need to be maintained and occasionally repaired. The issues surrounding this topic effect space planning, equipment organization, fab layout, and other areas. Repair and maintenance is more important in an automated fab than in a manual fab, so it should be planned for from the beginning.

A major part of the maintenance issue centers around the concept of a repair area. The repair area is simply the area required to "open the doors" on a machine and get to it for repair. The repair area should include the space occupied by the technician and any additional tools or test sets required to accomplish the work needed on the machine. A repair area does not exist all the time, but rather comes into being when repairs are needed on a piece of equipment.

Most equipment has a repair area that overlaps the activity envelope of a robot that would be loading the equipment. This overlap may cause problems if the robot is unable to load other process equipment because of the restriction within its activity envelope. AGV's present a similar problem, since a repair area could effectively block the AGV's path and prevent access to equipment downstream of the repair area. Similar problems with human access may exist in the chase area. A full chase area may become impassable once the access panels to equipment are opened and the technicians begin work, and equipment deeper in the chase may be inaccessible. There are several reasonable solutions to these problems, but the volume of the fab and reliability of the equipment will effect which solution is chosen.

The simplest solution is to make the repair area off limits to the material handling system and live with the consequences. If the overlapping repair area is not one that is used often, and the volume required of the cell can accept the loss of several units of process equipment for the length of the repair, then this is a simple solution. Some care must be taken in the control computer's scheduling of material to insure that time critical material does not get stuck if a repair area becomes active. For example, if the pre-diffusion clean station becomes inaccessible when furnace 3 is being worked on, then the controller should advise the user of this fact, stop new material from going to pre-diffusion clean, and wait for the material currently in work to finish before the repair is permitted. This type of complexity is only needed in locations where the timing between processes is critical.

Because of the low volume of Sandia's facility, the relatively simple solutions concerning repair areas are usable. The scheduling module in the cell controller allows the ability to look ahead to make sure that all equipment needed for a lot is available, and this look ahead can be performed more than once for a lot in order to prevent the start of a time critical step if the next position is unable to receive the lot. The cell controller can also identify, and mark down, equipment that becomes inaccessible when other equipment is under repair. The cell controller also understands an "about to go down" state that allows equipment to finish processing, but prevents new lots from being scheduled for it. Clearing an area for repair still requires final approval from an operator before the equipment goes down for repair along with the equipment that becomes inaccessible. Additional improvements in the software are needed before this becomes a completely automatic operation.

Another area that requires attention is the failure of the facilities themselves. Whether it is as dramatic as a total power failure or as common as a container running out of a chemical, failures in the facilities infrastructure should always be considered in a fully automated facility. Many times there is precious little that can be done to recover from such a failure, but process equipment and cell controllers should be able to recognize a failure and take whatever actions can be taken to limit the damage to the product.

Examples of designing for facilities failures would include items such as: an uniterruptible power supply (UPS) for an automated wet bench that would allow the bench to remove material from etch baths in the event of a power failure, sensors to detect lack of gas flows or low levels of chemicals in supply tanks, and controller software that can recognize a failure and treat lots exposed to facilities failures in a special manner. These are just a few examples, but features of this type will be very valuable when equipment fails during processing.

Flexibility

Many semiconductor fabrication facilities that deal with low volumes must also deal with a large mix of products. This mix may also change over time. As a result, flexibility is a highly desirable trait to have in such a facility. Many aspects of the facility, from layout and building design to the choice of equipment and material handling systems, are effected by flexibility choices, and flexibility is often achieved at some cost, so the trade-offs should be examined early in the planning stages.

Conclusions

Automation is a powerful tool for manufacturing, but requires advanced planning for maximum efficiency. This paper has touched on a few of the areas that require attention, and made some specifics based on experiences at Sandia. Not all these suggestions will make sense for all facilities, but the organization of the facility, the space to house it, and planning for maintenance and repair should be key items in any plan for a fully automated facility.

SANDIA AUTOMATION ARCHITECTURE

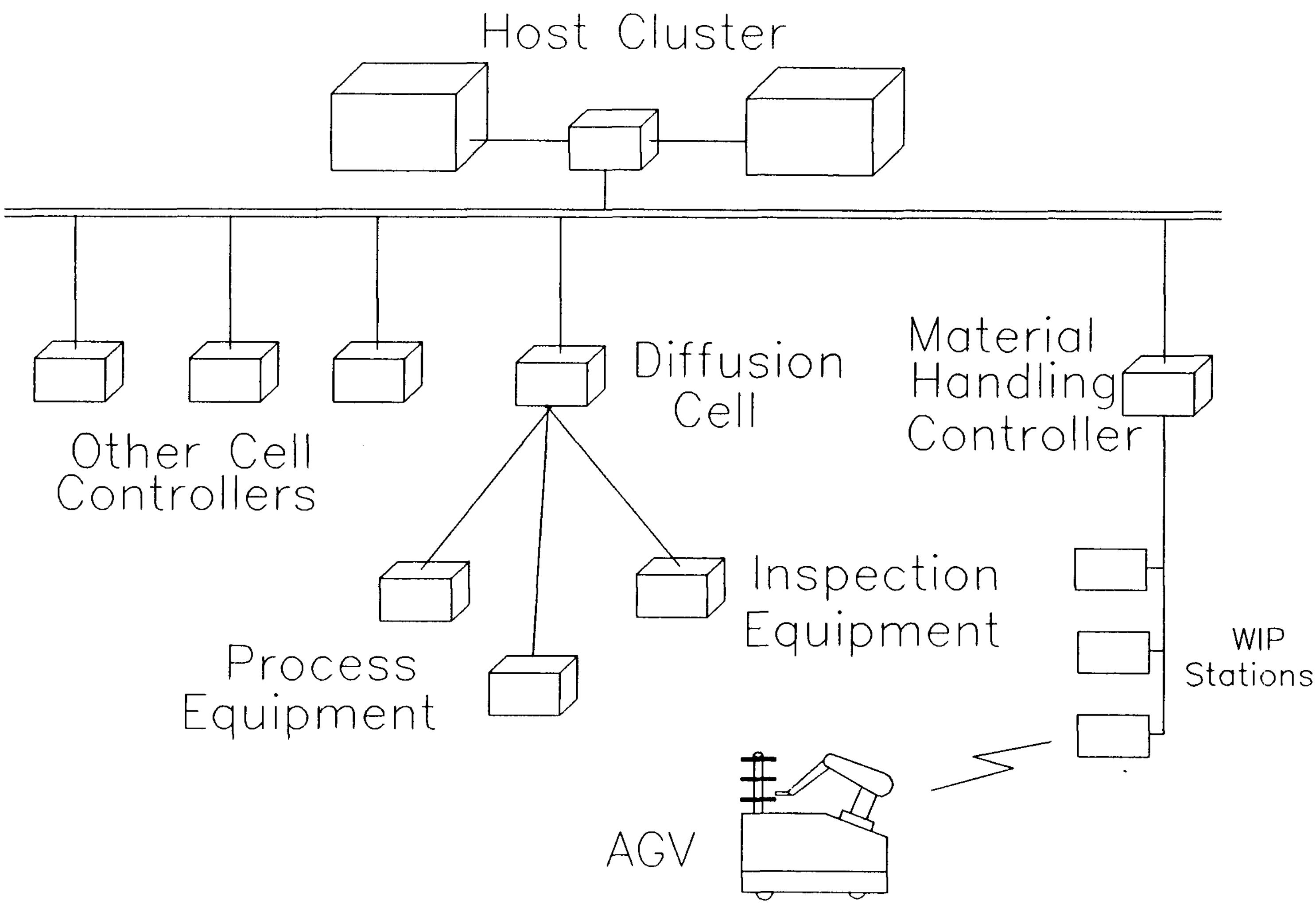

Figure 1