A New Low Cost Approach in 200 mm and 300 mm AMHS

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Abstract

There has been quite some speculation in the semiconductor industry recently with regard to the transition to 300 mm wafer fabs. In the meantime, it seems obvious that the ambitious time schedule will experience some changes and a severe delay. This delay in the launching of 300 mm wafer fabs forces the semiconductor industry to consider further improvements of 200 mm automation scenarios both in CIM/MES and AMHS. In this paper a new low cost approach for an automated material handling system (AMHS) was investigated using a conveyor system for interbay transport and intrabay WIP buffering located on the subfloor of a wafer fab. For the first time a model wafer fab was simulated with a conveyor system responsible for the complete material handling. In comparison to the typical scenario where operators are responsible for lot transportation, the simulation results indicate that a conveyor system does not have a negative impact on the key performance parameters of the wafer fab such as cycle time, WIP, and throughput, which probably can not be said for other types of AMHS systems. The AMHS system was built according to the results of the simulation conducted with the discrete event simulator AutoMod/AutoSched to provide improved production flexibility and to minimize the system and operational costs. Initial industry comments favour this concept. One advantage of this new approach is that it certainly helps to build experience before launching 300 mm AMHS automation.

Introduction

The semiconductor industry is driven by technology and process innovation that requires large expenditures to accomplish those innovation requirements. Return on investment has become more and more critical. Besides process tool costs, costs of automated material handling systems (AMHS) are becoming one of the significant wafer fab costs. Recently, wafer fabs have been built with 3 to 5% AMHS share of the total costs. In the meantime, some of those have been shut down and the use of those expensive tools and handling systems will never see a return on their investment. Since the latest crisis in this industry fab-manager performance is even more likely to be evaluated by economical results. Before taking investment decisions, owners or shareholders will have to be convinced by economic justification.

Key players in wafer fab automation have lobbied and influenced the 300 mm standards. Several studies have been published to prove their concepts on 300 mm wafer transportation [1-4]. Those standards are certainly overpowered for 200 mm applications and so are many other existing AMHS concepts. Standard systems based on intrabay stockers and interbay monorails often exceed a cost of 30 million $US. The downtime costs of such systems are, of course, extremely high.

The delay in the introduction of 300 mm wafer fabs, caused mainly by the unavailability of mature process equipment, will force the industry to improve existing processes and to increase the productivity of the existing equipment. Also, existing CIM/MES architectures will experience further upgrades in functionality and sophistication. Wafer transportation in existing wafer fabs will be tackled with new scenarios. The industry has recognized that the 200 mm wafer fabs have to generate revenue in the next couple of years. So the delay will generate an ideal means to gain experience for the 300 mm enterprise which will mainly start after the next crisis, which is expected in the years 2003 and 2004.

This is why inexpensive and more flexible AMHS are required now, systems which can be upgraded and easily modified and which are able to transport the existing 200 mm open wafer carriers or SMIF pods, but can also be modified to transport 300 mm FOUPs relatively easily. In the best case those AMHS will be able to convey both types of wafer carriers on the same system hardware.

The new low cost AMHS approach presented in this paper has taken the lessons learnt from 200 mm projects and adapted its features to the new requirements of the semiconductor industry. The main properties of this new system are:

- Modularity and flexibility
- Better price performance per delivered wafer carrier
- Just-in-time delivery
- Easy product allocation in ASIC fabs (engineering and other hot lots)
- Easy interface to PGV, AGV, and monorail.

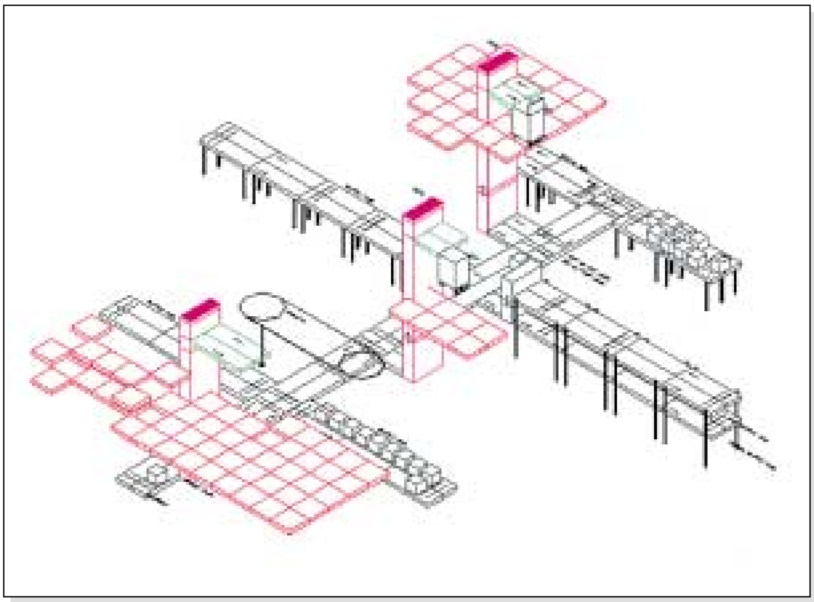

Figure 1
Principle of the new conveyor transportation and local buffering system

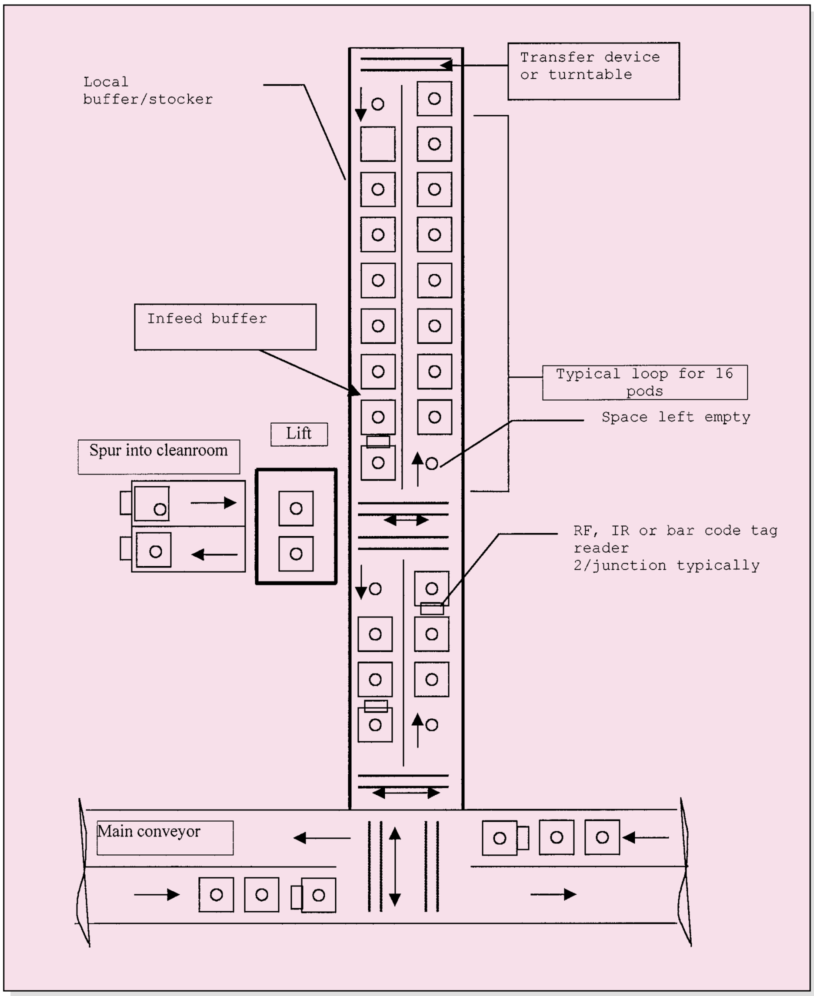

Figure 2
Scheme of an intrabay buffer conveyor loop

Standard state-of-the-art AMHS can not be used for all wafer fabs as they all have different product process flows. Wafer fab simulation has to be performed to define the maximum utilization of the process equipment and to reduce the work in process (WIP) buffer to a minimum. As process flows increase in complexity, there is a growing competitive pressure to reduce cycle time and WIP. There is a continued drive to dramatically increase output and, at the same time, decrease production costs. In comparison to the centralized stocker concept, localized storage of WIP wafers can provide a major breakthrough in realizing this performance goal.

The numbers of clean product AMHS have risen significantly over the past 3 years. This growth has been driven mainly by enhanced demand for cleanliness, and the requirements of increased product yields and decreased overall process costs. The reduction of product handling will also increase the demand.

This new low cost AMHS approach is a conveyor system-based transportation and dynamic buffering AMHS, where the size of the WIP buffers of the intrabay buffer loops are specified by wafer fab simulation. It is a customized AMHS, i.e. it is geared towards the specific needs of an individual wafer fab and corresponds to the production philosophy or product mix defined on its shop floor. It is important to note that an already designed conveyor system will accommodate future changes in production philosophy, i.e. if the conveyor system has been designed and gone into operation, any future change in the operational characteristics of the shop floor (changes in product mix, lot release plan, number of products, etc.) can be mapped into the existing simulation model of the shop floor to determine the new requirements for this conveyor system. Due to the flexibility of its architecture, the conveyor systems hardware will then be adjusted and upgraded with respect to the new production scenario.

IMPLEMENTATION OF AN INTERBAY TRANSPORTATION AND INTRABAY BUFFERING AND POD DELIVERY

The standard state-of-the-art AMHS systems consists of the following elements:

- An interbay monorail conveyor with stationary stockers at endpoints.
- Interbay and intrabay monorail conveyors with stationary stockers at critical process bays or tools.
- An interbay monorail conveyor and intrabay personal guides vehicles (PGV) or automated guided vehicles (AGV) with stationary stockers at selected stations.
- An overhead intrabay conveyor with dynamic vertical stacking buffers at selected process tool points or critical stations.
- Any of the above supplemented by manual carts, racks or rolling shelves.

The challenges presented by the concept described above are threefold:

1. First, components of the intrabay system tend to be expensive, especially when large stockers are used to buffer WIP wafers. Since these stockers tend to be costly, they are usually centrally located and can be process bottlenecks in locations of highly utilized tools.
2. Secondly, stockers tend to be very large, taking up expensive and valuable clean room floor space. They are generally located in central areas, and often do not serve intrabay operations effectively. This is especially true in applications where large numbers of wafers are undergoing many different complex operations.

3. Thirdly, breakdown of a centralized buffer often results in the failure of just-in-time delivery of WIP wafer pods, causing expensive process equipment idle time and process inflexibility.

The new low cost AMHS approach intends to improve cost of ownership and at the same time increase the utilization of operational floor space by minimizing the need for some or all intrabay stockers systems or racks.

This new transportation and local buffering system (Figure 1) uses interbay transport and intrabay dynamic buffering, servicing the process clean room from the subfloor or from the plenum. The system has to be Class 1 to 1000 compatible, according to FED STD 209E. The intrabay buffering system works with interbay transport systems through the use of four basic components:

- Small localized, close proximity, intrabay buffer conveyor loops
- Vertical lift conveyors with input/output spurs into the clean room
- Clean pass boxes between the elevator and the subfloor or plenum
- Localized electronic PLC control system working in conjunction with factory material control system (MCS).

The intrabay buffer conveyor loop (Figure 2) is a short run, bidirectional conveyor that forms a closed loop system and receives wafer pods directly from an interbay conveyor running outside a clean room floor, or from a vertical lift discharge spur that delivers pods from the process area. The intrabay buffer conveyor loop can store and retrieve small numbers of pods (SMIF, FOUP or open cassette), such as 8 or 16, if used directly for a tool process buffer (i.e. for an exposure machine), or a larger number of pods, such as 32, 48 or 64, if used for several sequential tools (i.e. for wet etching). In the case of space problems, multi-stage conveyor loops can be built. The whole system can be encapsulated and equipped with additional HEPA or absolute filters to rinse the pods during their stay on the buffer or during transport through the elevators.

The pass boxes are designed to overcome the delta pressure between the clean room and the subfloor or plenum and to clean the air. If the subfloor or plenum is significantly less clean than the operation area, the pass box will provide a clean air shower to the pods being brought into the clean area, such that the products being delivered to the shop floor have at least the same quality in terms of cleanliness. An enhanced cleaning process can be invoked by the addition of ionisers in the pass box.

The vertical lift (vertical conveyor) transports pods through an opening in the shop floor. The lift places the pods (typically one or two at a time) on a short interface conveyor in the clean room such that the pods can be added or removed by several traditional movement processes (a manual transport, PGV, AGV, or overhead monorail conveyor).

The intrabay buffer control system (Figure 3) uses a series of programmable logic controllers (PLCs) and/or personal computers (PCs) and data storage units to provide control to the individual local conveyor buffer and vertical lift. The intrabay buffer controller receives its input/output data from the MCS system. Each wafer pod must be equipped with a bar code, IR or an RF tag, or some other form of real time identification. When called by the MES or FMS or local tool controller, the pod's tag in the buffer will be read by sensors or readers and the proper pod will quickly be routed to a proper

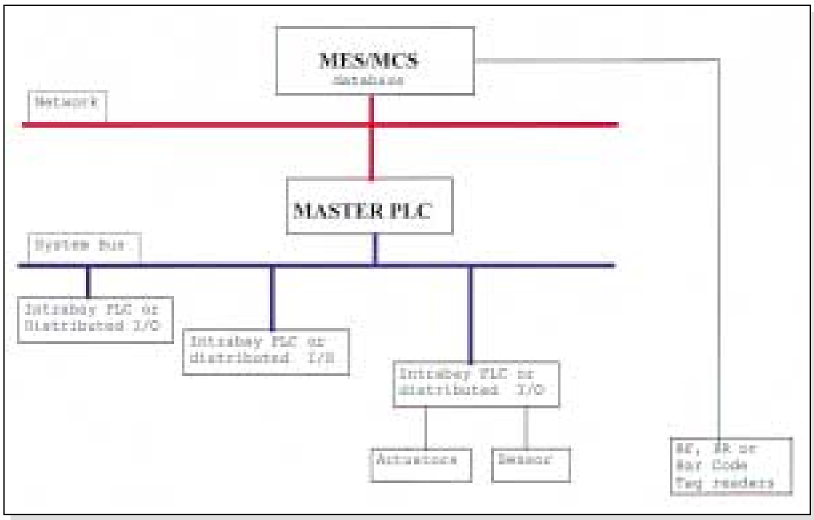

Figure 3
The use of distributed controls and I / O for safety reasons and modularity

Table 1. Operational Characteristics of AutoMod/AutoSched Simulation Model

Equipment set	80 tools
Equipment characteristics (WPH/MTBF/MTTR)	data sheets (WPH) and empirical data base (MTBF/MTTR)
Working period	24 h/day, 7 days/week
Products	2 Product types (P1, P2)
Product mix	P1 : P2 = 1 : 2
Wafer starts	9.000 WSPM / 110.000 WSPY
Rework & yield	0% and 100%, respectively
Lot release policy	Bunched lot starts (6 lots) once a day
Lot dispatching rules	FIFO / FIFO-Batch
Batch criteria (furnaces) Batch criterion (other batch equipment)	Same process step, same process time Same process step
Lot size	50 wafers/lot
AMHS Conveyor	6 vertical lifts in front of each bay, pass box integrated. 1 interbay conveyor system on subfloor 6 intrabay buffer conveyor loops on subfloor conveyor speed: 5 m/min; no section motor downtime
Staffing level (operators per 8 h shift)	Photo: 4 Diffusion: 3 Implantation: 2 Wet etch: 3 Plasma etch: 2 Metal etch: 3

vertical lift. The pod will rise through the process floor and be presented on its stub interface conveyor, awaiting a transport vehicle or operator to take it to the requesting tool or location.

SIMULATION MODEL OF THE NEW LOW COST AMHS APPROACH

To prove and evaluate the new low cost AMHS approach, a representative wafer fab was modelled with the discrete event simulator AutoMod/AutoSched. Although in standard literature conveyor systems have been regarded as a potential option for AMHS, this paper presents the first model wafer fab being simulated with a conveyor system for lot transportation [5]. The aim of this simulation project was to determine the influence of the conveyor system described above on the production performance of the model wafer fab. Two typical 0.25 µm process flows were released into the fab with approximately 250 and 300 process steps, respectively. The operational characteristics of the wafer fab under investigation are compiled in Table 1.

The conveyor system was located on the subfloor of the model wafer fab (Figure 4). Each intrabay buffer conveyor loop was located exactly underneath the corresponding bay of the shop floor. Outside each bay on the shop floor a vertical lift was positioned that allowed the transportation down to the conveyor system with subsequent transportation to the intrabay buffer conveyor loop relating to the lot's next process step or the transportation in the upward direction, where the lot would be picked up by the operator and carried to the next bay.

With regard to lot transportation, two operational modes were defined for the model wafer fab. The first mode, the operator transportation mode, is the mode of operation found in the majority of today's wafer fabs. Lots are released into the wafer fab and start from the incoming rack in front of the first bay of their route which is the diffusion bay. The constraint generally put on each operator was that an operator assigned to a certain bay was only allowed to do setup and processing on the equipment of his bay and then transport the lot within his bay or to the next bay as given in the routings of the two product types. There, the operator of the next bay would pick up the lot from the bay's incoming rack and continue according to the same scheme.

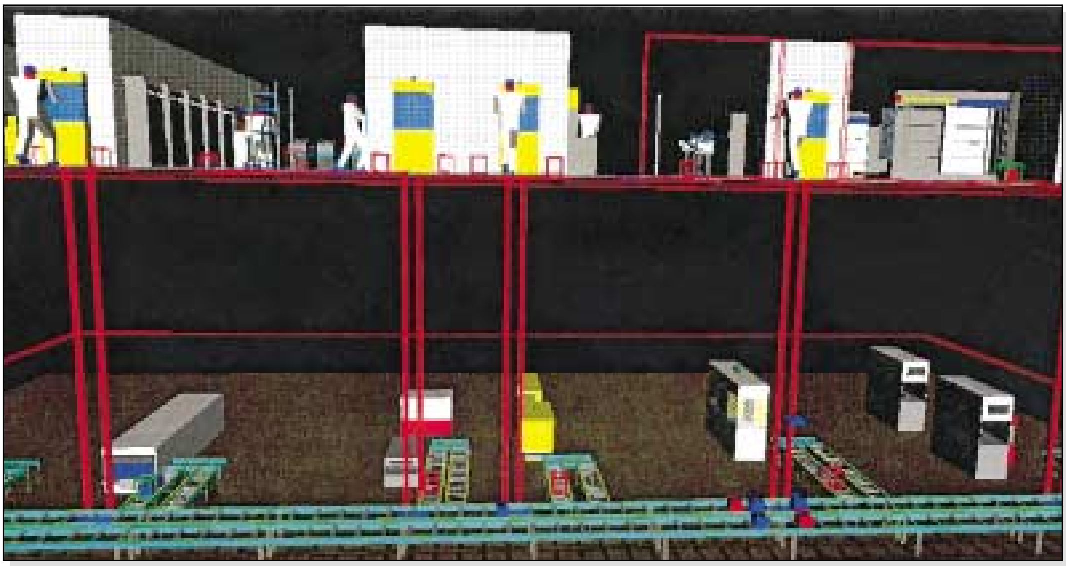

Figure 4
Model of wafer fab process bays and conveyor system on subfloor

Figure 5
Animation of subfloor interbay conveyor and intrabay buffer conveyor loops

The second mode, the AMHS conveyor transportation mode, integrated the conveyor system. Lots are released into the wafer fab and start from the incoming rack in front of the first bay of their route, which is the diffusion bay. The diffusion bay operator picks up a lot and begins with the various process steps in the diffusion bay. After completion, the diffusion operator carries the lot to the vertical lift positioned in front of the diffusion bay and the lot travels down to the subfloor conveyor system. According to its route, the lot travels via subfloor interbay conveyor system to the intrabay buffer conveyor loop of the bay it will be visiting next. There, the lot is buffered and starts its itinerary to the vertical lift as soon as it is requested (via the MES/MCS-system) by the equipment it will be processed by next, i.e. the first equipment in the bay; simulation-wise, the station family queue of this equipment is located on the buffer conveyor loop. This equipment will from now on be referred to as entry equipment. The operator of the corresponding bay will pick up the lot at the vertical lift and continue according to the same scheme.

RESULTS

The key performance parameters investigated in the simulation model for both transportation modes were cycle time and WIP distribution for the two products. The time horizon for the simulated model wafer fab was set to one year; for the operational characteristics defined in Table 1, simulation runs were performed for the operator transportation mode and then for the AMHS conveyor transportation mode. To toggle from the first to the second mode, new product route files were imported into the simulation model defining new itineraries (in contrast to the standard itineraries of the operator transportation mode) that forced the lots to utilize the complete conveyor system. The results with regard to the two performance parameters are compiled in Table 2.

As can be seen from Table 2, the introduction of the AMHS conveyor transportation mode does not alter the two key performance parameters of the model wafer fab. The neutral effect of this mode can also be seen, looking at the results regarding equipment and operator utilization as well as throughput.

Another important set of key performance parameters for the AMHS conveyor transportation mode is the set of intrabay buffer conveyor loop statistics. Table 3 compiles the utilization and statistics for each intrabay buffer conveyor loop integrated in the model wafer fab. With respect to the integration of an AMHS system based on conveyors, both the design of a new wafer fab and the upgrade of an operating wafer fab require reliable data to plan the AMHS system. After simulation of the customer's wafer fab, the set of intrabay buffer conveyor loop statistics allows a precise planning of the conveyor system with regard to capacity and corresponding hardware costs. Since wafer fab simulation determines the average amount of lots as well as the minimum and maximum amount of lots buffered on each individual intrabay buffer conveyor loop, each subfloor buffer conveyor loop can be exactly matched to the specific production scenario on the shop floor. This information also determines the capital investment into automation of the wafer fab. The model wafer fab, for example, requires an intrabay buffer conveyor loop for photolithography that accommodates a peak buffer load of 66 lots (Table 3). Taking into account a pod size of 25 cm for 200 mm lots, this peak loads equals 17 m of photolithography intrabay buffer conveyor loop. Assuming costs of US$ 20 000 for one metre of conveyor hardware and software, the total cost for this intrabay buffer conveyor loop equals US$ 340 000. Accordingly, the whole system of intrabay buffer conveyor loops, interbay conveyor and intrabay elevators utilized in the model wafer fab equals US$ 2 340 000, exclusive of engineering, installation, and MES user interface.

Table 2. Average Flow Factor and WIP for Both Modes of Operation

Key performance parameters	Operator transportation mode		AMHS conveyor transportation mode	
	P1	P2	P1	P2
Average flow factor	2.66	3.23	2.69	3.29
Average WIP	56.32	91.34	57.12	93.30

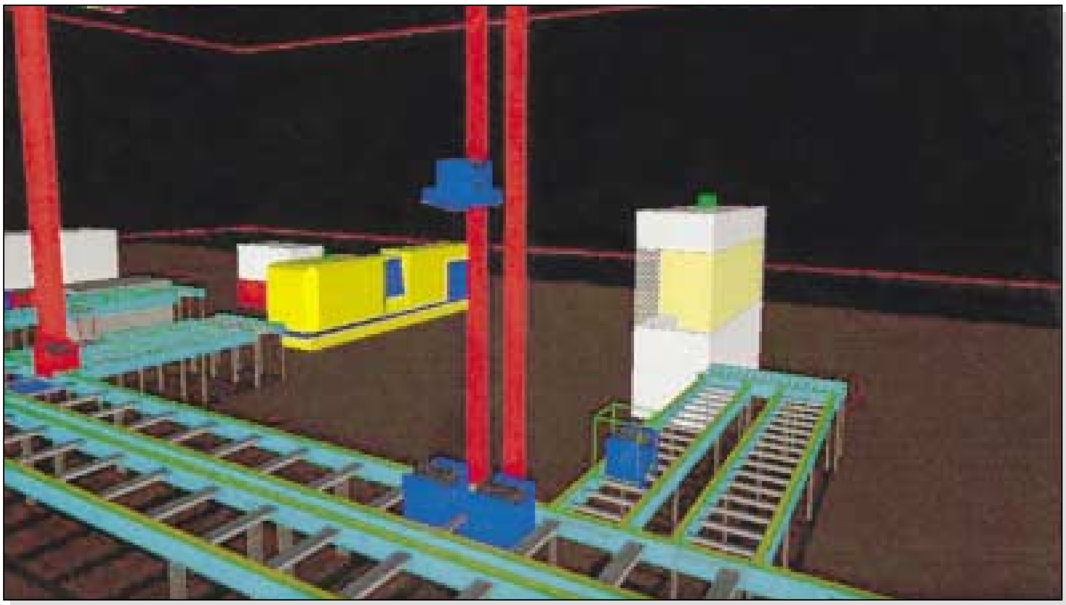

Figure 6
A batch of lots getting ready for transportation on the elevator system

Table 3. Intrabay Buffer Conveyor Loop Utilization Summary for 90% Uptime of Set of Entry Equipment

Intrabay buffer conveyor loop	Max. amount of lots	Min. amount of lots	Av. amount of lots	Av. lot wait time (s)
Photolithography	66	0	4.96	5968
Diffusion	57	0	10.24	8068
Implantation	7	0	0.13	265
Wet etch	10	0	0.96	1100
Plasma etch	37	0	12.34	23296
Metal etch	22	0	4.60	8343

Table 4. Intrabay Buffer Conveyor Loop Utilization Summary for 80% Uptime of Set of Entry Equipment

Intrabay buffer conveyor loop	Max. amount of lots	Min. amount of lots	Av. amount of lots	Av. lot wait time (s)
Photolithography	109	0	14.64	17539
Diffusion	76	0	20.59	16096
Implantation	10	0	0.53	1097
Wet etch	12	0	1.16	1314
Plasma etch	38	0	15.67	28509
Metal etch	24	0	5.62	9763

It is obvious that the set of entry equipment plays a vital role in the design of the intrabay buffer conveyor loops. This set includes, for example, equipment for pre-diffusion clean, vapour prime, and implantation, i.e. the first process steps in the diffusion, photolithography, and implantation bay, respectively. Since lots are buffered on the intrabay buffer conveyor loop to await their processing at entry equipment, the performance of this set directly determines the design of the intrabay buffer conveyor loop. The results compiled in Table 2 and Table 3 correspond to an uptime of 90% for the set of entry equipment. For an uptime of 80% for the set of entry equipment, the simulation model provided the data shown in Table 4.

As can been seen from Table 4, the case of 80% uptime for the set of entry equipment requires, for example, an intrabay buffer conveyor loop for photolithography that accommodates a peak buffer load of 109 lots. Taking into account a pod size of 25 cm for 200 mm lots, this peak loads equals 28 m of photolithography intrabay buffer conveyor loop. Assuming costs of US$ 20 000 for one metre of conveyor hardware and software, the total cost for this intrabay buffer conveyor loop equals US$ 560 000. Accordingly, the whole system of intrabay buffer conveyor loops, interbay conveyor and intrabay elevators required for this case equals US$ 3 660 000.

One evident conclusion is that the set of entry equipment requires very special care and thought since it directly influences the design and the costs of the conveyor system. In the case of a new wafer fab being under consideration with a conveyor system, only high performance equipment should be evaluated from the customer's point of view. High performance here relates to low processing times, maximum batch sizes as well as reliability. The latter should be supported by an intelligent PM schedule that is sensitive towards the special role of entry equipment and its interaction with the intrabay buffer conveyor loop. In the case of an operating wafer fab that will be retrofitted with a conveyor system, the PM schedule of the set of entry equipment is also of vital interest.

Benefits and Advantages of Local Buffering

Faster batch delivery by pre-sorting of wafer pods

The local intrabay buffers are divided into small sections or loops. By adding readers onto these loops, the pods can easily be pre-sorted according to the FIFO principle or other dispatch rules. This is very important to shorten the load time of batch processing tools. Finally, this can lead to a reduction of intrabay operators employed.

Easier product allocation

Especially in ASIC foundries, flexible product allocation is often requested by the customers. In this case the batches can be easily relocated on the local buffer to have a faster access. There is no need to send the previously selected batches to a central buffer. They can stay with the buffer until the next request.

Improved /easier process flexibility due to buffer system modularity

If new groups of tools have to be added or the process floor has to be reorganized, the new system can easily be adapted to the new situation. The hardware of the conveyor buffer is built of small modules which can be easily repositioned. Hot lots as well as engineering lots can be handled by this concept.

Improved safety and ease of maintenance in comparison to standard stockers

The conveyor is running with a low speed of approximately 5 m/min because there is no need for higher speeds. All the critical moving and contaminating parts are protected by a cover or a plenum. The interaction with the operator on the shop floor is reduced to a minimum. System preventative maintenance is easily accomplished due to the modularity of the system. Maintenance of one buffer does not require the shutdown of the whole system. Other local buffer loops can be used to maintain the product flow during a sector maintenance shutdown.

Yield improvement by electrostatic discharge control

It is well known that cleanliness of equipment is mandatory, but another phenomenon, electrostatic discharge (ESD), is an important element in yield and reliability improvement of sensitive semiconductor devices. Without controlling ESD, this can lead to damage of gate oxide layers and cause the frightened latch up effect or reduce the life time and reliability of the product.

ESD controlled AMHS systems by using conductive or resistive controlled materials reduce an impact on process yield. Almost every conveyor hardware manufacturer is able to fulfill this specification by using conductive materials.

Today, conveyors with low ESD voltage levels can be built. A maximum triboelectric voltage charge of 10 V can be achieved and fulfills herewith the requirements of the semi-conductor industry. With special arrangements, levels of less than 1 V can be reached. This will be of special interest for battery powered devices such as integrated circuits for smart cards, watches and toys.

Simple interfacing with existing stockers, overhead monorail conveyors, pgvs, and agvs

A conveyor system can run on different levels of the factory. The input or output spur is a simple interface so that all kinds of transport and tools can be adapted. Also, future intrabay expansion can be easily realized.

Better cost of ownership per delivered pod

Due to the reduction of initial system costs and lower maintenance costs, a better price performance per delivered pod can be achieved. The reduction of clean room floor space is another major cost saving factor. In our simulation model with an equipment uptime of 90%, and assuming a system depreciation of 5 years, the cost of ownership would be 120 $US per processed wafer pod.

SUMMARY

A new low cost approach in 200 mm and 300 mm AMHS using a conveyor system has been presented, showing that this approach is a potential option in both 200 mm and future 300 mm wafer fabs. For the first time, such a system has been modelled as part of a representative wafer fab. The results of the simulation project show that the conveyor system does not alter the key performance parameters of the model wafer fab under consideration.

There are several advantages that need to be highlighted: it is well known that a conveyor based system simplifies material transport. It allows a higher transport flow rate than any other system. It brings the wafer carriers close to the process floor. The installation of such a system has no limitation for future expansion. Conveyors are now zone controlled and the moving parts are reduced to a minimum. Cleanliness issues are greatly minimized. System modularity allows the system to grow with the process.

Also, investment need not be done at once. A discrete event simulation conducted in advance will define the WIP buffer size. Future changes in shop floor operation that require an upgrade of the AMHS can then be easily supported by discrete event simulation.

Each wafer fab has its own typical processes and product mixes, thus standard solutions can not be offered. Each new AMHS system has to be adapted to the production philosophy and it is obvious that only a wafer fab simulation project can define the correct size of the whole system to a higher degree of accuracy.

Finally, a conveyor based AMHS has a high throughput, low fixed and variable costs, low running costs and needs less floor space. Such a system is more flexible due to modularity and can be easily adapted to other systems.

Future work will investigate whether the use of smaller lot sizes (13 and 25 wafers/lot) will gain in asset productivity and influence transportation, cycle time, and WIP, taking into consideration that in this case the production scenario has to be changed according to the specifications of the equipment. It will question the simple theoretical statement that a reduction of lot size always leads to a better throughput or line performance. It will not use a neutral factory model [6] but will focus on a typical mixed technology ASIC factory. Also, the influence of various dispatch rules (critical ratio, etc.), order launch methods (KanBan, constrained-based WIP management), batch size policy (greedy versus full batch for batching entry equipment), and engineering as well as hot lots will be investigated thoroughly for the operator transportation mode and AMHS conveyor transportation mode. Stochastic events that influence the performance of the conveyor system (for example, downtime of section motors) as well as planned downtime (due to service) will be simulated with their corresponding back-up scenarios.

Finally, the new lost cost approach in 200 mm and 300 mm AMHS presented in this paper will be combined with another promising concept, the Sea of Lots. Since the introduction of mini-environments and the use of turbulent airflow patterns in the clean room, the plenum, which is a clean area above the clean room ceiling, became empty. Thus, an ideal place to store and transport WIP. A very interesting new approach, the so-called Sea of Lots (SOL) was introduced at Semicon Europe 1999 by the consortium Krantz-TKT and Ortner CLS. The intrabay buffers are replaced by flat stockers which are located in the plenum just above the intrabay [7].

A fast robot serves the pods via a vertical transfer unit to an I/O port or straight onto the process equipment. The vendor promises pod delivery time from the flat stocker to the I/O-port in less than 1 minute. This approach is adaptable to any kind of process technology and can be built in megafabs as well as in small ASIC fabs. The flat stockers are located so close to the equipment that the need of an equipment buffer is not required. That is why the vendor calls the flat stocker a cell equipment buffer (CEB). The interbay is performed by a zone controlled conveyor system. Also important is that this system can be easily converted from 200 mm to 300 mm. The system uses standard components which have been proven in the automotive industry under heavy duty conditions for several years. All elements are built to conform to class 100 according FD STD 209E. All this should result in good MTBF values. It is the aim of future work to investigate the

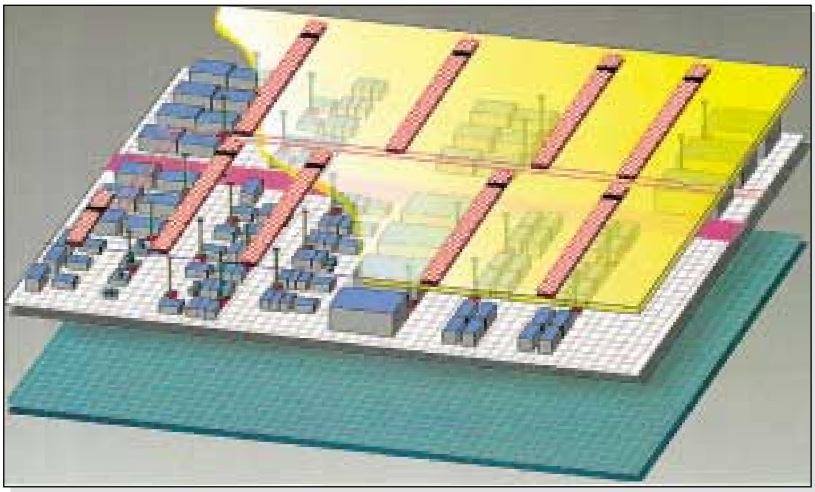

Figure 7
Sea of lots concept
(courtesy of Ortner CLS Dresden)

impact of both conveyor AMHS and Sea of Lots on production performance and to show that this integrated concept offers a promising option to the 300 mm enterprise.

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