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EFFECTS OF METROLOGY LOAD PORT BUFFERING IN AUTOMATED 300MM FACTORIES

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ABSTRACT

This report describes a simulation study characterizing the advantages and disadvantages of implementing multiple load ports on metrology equipment in a semiconductor factory. Three methods of automated material handling (AMH) for 300 mm wafer carriers in four separate models were analyzed: Through Stocker, Point-to-Point, and Conveyor (slow and fast velocity). Parameters measured include idle times of metrology equipment as number of load ports change and the effects on bottleneck equipment, work in process (WIP), queue lengths, transport times, delays waiting for transportation to begin, and the effect on stocker utilization by bay.

1 INTRODUCTION

During 2001, public models were created to demonstrate the capabilities of automated material handling systems for 300mm manufacturing. These models were created not only as a benefit for International SEMATECH (ISMT) member companies as a mechanism for studying the strategic direction of their fab operations but also, to test the capabilities of commonly used semiconductor simulation software. The models developed use three different mechanisms for material handling; Through Stocker transport, Point-to-Point, and Conveyor. These models were designed with a minimum of two load ports for all tools, including metrology. Specific tool groups have additional load ports. Comparisons and analyses were made in the metrology tool group on the effects of having single versus dual load ports.

Identical factories are used to test the factory effectiveness when choosing one of three material handling configurations. The AMHS configurations within the models contain criteria specific to each material handling system. Four models were developed to compare the three material handling options. The first is an overhead hoist transport system where OHT vehicles are designated as intrabay or interbay vehicles that travel only in their respective bays. All movement is through stockers located at the head of each bay. The second model is a merge/diverge vehicle system in which lots may travel point-to-point using stockers for overflow storage only. Vehicles are allowed to move between bays in this model. The third (and fourth) model is a conveyor system in which lots travel point-to-point on a conveyor and primarily use the conveyor sections as their overflow storage. If the conveyor sections are at capacity, then one of four stockers serves as storage.

Although in-line metrology equipment in our original models have a two load port configuration, an inherit amount of excess capacity exists in the metrology tool group. This study attempts to use simulation to investigate the need for dual load ports in metrology equipment in a fully automated semiconductor factory. A second order effect is observed due to the performance of the most common implementations of AMH systems with respect to impact upon the semiconductor factory's delivery performance.

2 BUFFERING BACKGROUND

Factory guidelines developed at ISMT in 1997 as part of the International 300mm Initiative program pioneered the standards for load ports on semiconductor process and metrology equipment. As part of the guidelines, all in-line process equipment (tools required in the process) requires a minimum of two E15.1 compliant load ports (Ferrell and Pratt 1997).

Manufacturing strategies requiring equipment to process continually necessitate simple and reliable buffering on high throughput, bottleneck, and batch process tools. Buffering on equipment reduces the amount of idle time spent waiting for lots to be delivered. With two load ports, the capability exists for metrology equipment within the models to process continually and increase the effective throughput of the equipment and therefore, increase equipment productivity. During continuous processing, all pre-processing is completed on a lot before the tool requests that lot for processing. Additional load ports help to segregate the performance of process equipment from the performance of the lot delivery system.

With the added benefit of continuous processing, additional lots can be processed in the same time frame. This can be seen in Figure 1, where one additional lot is processed using continuous processing. Load ports must be capable of continuous operation. Lots are in queue waiting to be processed while other lots are being processed. A common configuration for single lot tools is to have one lot in process and one lot buffered. The modeling that was completed for this study assumes that the load ports use minimum footprint and meet all guidelines and standards (Ferrell and Pratt 1997). The cost of load ports was not considered as a factor in this study.

With intrabay automation, microstocking can be an effective way to keep WIP flowing to down stream tools. Utilizing multiple load ports is an acceptable form of microstocking. Having a minimum of two load ports in effect provides a small but limited microstocking capability. Studies have shown improvements in overall fab performance when idle time is reduced (Campbell and Norman, 1999).

3 AMHS BACKGROUND

The migration to 300 mm silicon wafers represents the latest in a series of transitions in silicon wafer diameter to have occurred over the past 30 years. This transition incorporates several related changes in material handling technology not found in previous generations. The most significant paradigm shift is the requirement for fully automated process tool-to-process tool material scheduling and delivery and a totally new wafer carrier design. Automated material handling systems (AMHS) for 300 mm can be implemented with a variety of approaches, each having different performance characteristics.

First generation 300 mm wafer facilities were constructed with automated delivery of material only between process bays; i.e., "interbay." Movement of this type consisted of moves from one stocker to another stocker, having stockers at the end of each process bay and using material handling technology similar to that found in 200 mm wafer facilities. Wafers were delivered within process bays (i.e., "intrabay") using person-guided vehicles (PGVs) or conventional WIP carts. These moves occurred from stocker-to-process tool or process tool-to-process tool. Productivity using this approach would be approximately the same as in 200 mm factories.

Second generation 300 mm wafer facilities are being implemented with interbay material delivery as in first generation facilities with intrabay material delivery using overhead hoist track (OHT) vehicles, automated guided vehicles (AGVs), or rail guided robots to deliver the material from the stocker to individual process tools within the bay. With this approach, the first steps can be taken to coordinate the delivery of material with process tool availability, thereby improving overall productivity of the factory. The interface from the interbay to intrabay AMH systems is through temporary storage of the material in a wafer stocker with physical connections to both interbay and intrabay material handling systems. In this study, this is referred to as the "Through Stocker" model. More advanced versions of the Through Stocker model provide the capability to deliver lots from process equipment to process equipment or from one intrabay to another bay without transferring through a stocker. This model is referred to as Point-to-Point.

The next generation of AMHS addressed is a direct process tool-to-process tool system that uses an overhead conveyor system (having no vehicles) for material movement coupled with local robotic handlers to transfer the carrier from the conveyor track to the process tool load port. This type of system is now being tested in pilot implementations and offers potential advantages over ve-

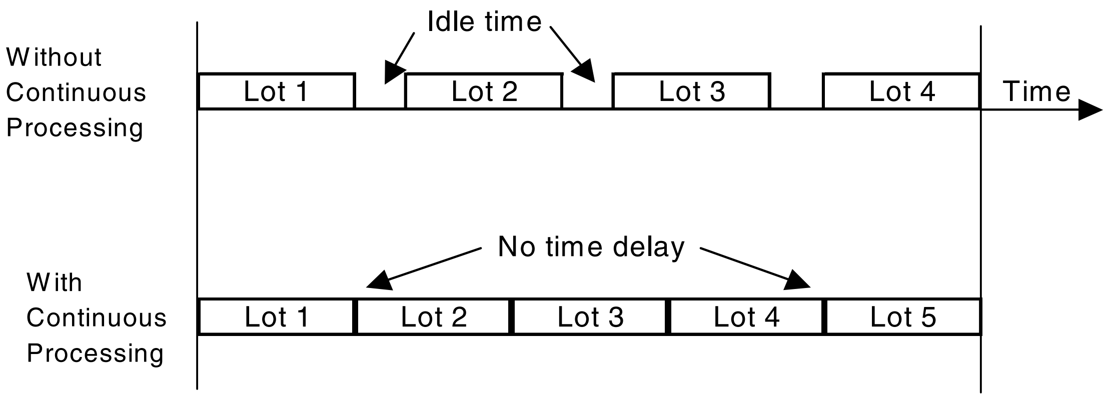

Figure 1: Output Improvement when Idle Time is Eliminated

hicle-based systems described above. In this study, this is referred to as the "Conveyor" model. The Conveyor model is simulated in two fashions. Since speed of delivery can be an issue for lot arrival times, Conveyors have been simulated in what would be considered a slow velocity and then again simulated at a rate of twice that of the slower velocity.

The systems described above were simulated for a complete 300 mm wafer factory using commercially available factory simulation software coupled with a common set of factory rules for wafer starts, process route/steps, and tool sets, including process and down times.

4 MODELING SOFTWARE

The software supplied by Brooks Automated Planning and Logistics Solutions for the discrete event simulation models described in this report is AutoSched Accelerated Processing (ASAP) v 7.1 and AutoMod v 9.1. ASAP is an object-oriented modeling tool that uses a Windows-based Excel spreadsheet interface. The ASAP model describes the factory elements such as tools, stockers, products, processing logic (routes), and scheduling logic.

The AutoMod software incorporates real-time virtual reality graphic animation, helping to validate the model and communicate the design visually. It also includes templates to accurately model material movement. The AutoMod model describes the factory layout, the material movement, and transport options and provides the graphics for the model. The model communication module (MCM) provides the communication link (socket) between ASAP and AutoMod. The MCM keeps the models in continuous synchronization with each other.

5 FAB LAYOUT AND DESCRIPTION

The fabrication facility modeled is a generic 300 mm facility with 20,000 wafer starts per month. The fab is fully automated, using either overhead vehicle or conveyor transport. It has one main interbay with 24 intrabays spaced evenly across as seen in Figure 2. The interbay is 500 feet long with a turning radius of 10 feet on each end. The intrabays are 100 feet long with a turning radius of 5 feet on each end. Within the intrabay are 24 possible locations for tools, spaced equally apart in the bays. At the head of each bay is space for two stockers.

The model uses a generic 130 nm copper process flow developed at ISMT. The process flow has seven metal levels and 23 mask layers. Ten products of the same routing and a small number of hot lots are modeled in the fab. Hot lots force setups at a tool without searching for a duplicate tool with the required setup and reserve a tool that is one step downstream while processing on an upstream tool.

The fab has 27 tool groups, totaling 330 tools. Tools are dedicated to the front-end or back-end of the process.

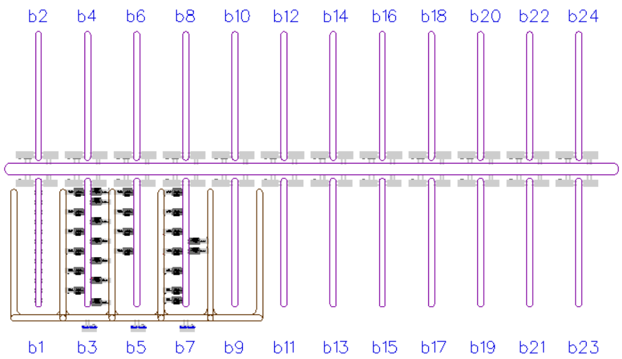

Figure 2: Fab Layout

Lots processed on a specific lithography tool at active area, gate, contact, metal 1, and via 1 are dedicated to that tool. Tools are grouped in a farm layout except for 56 metrology (including inspection) tools distributed throughout the fab. Inspection tools were not included when reducing load ports. Graphically, all tools are shown with two load ports. The total capacity of these load ports represents the total available storage at the tool. Storage capacity is four lots for lithography tools, ten lots for wet benches, twelve lots for furnaces, and two lots for all other tools. Wet benches process two lots in a batch while furnaces process a minimum of two lots and a maximum of four lots in a batch. Batching tools can process one hot lot at a time. The wait time for a furnace to build a maximum size batch is equal to half of its processing time. Furnaces have a 30-minute cool down built into the overall processing time.

6 MODEL VALIDATION

The model development is a result of 4 years of interaction between ISMT member companies, process engineers, simulation engineers, and simulation consultants. The model originated from work completed in Phase I & II of I300I. Documentation of the originating models may be found in the ISMT Technology Transfer documents: 300 mm Factory Layout and Material Handling Modeling: Phase I Report, published in February 1999 (Quinn and Bass 1999) and 300 mm Factory Layout and Material Handling Modeling: Phase II Report, published in November 1999 (Campbell and Ammenheuser 1999). Because the software used to create these models is no longer supported, the model was rebuilt by consultants at AutoSimulations, Inc. (now Brooks Planning and Logistics Solutions) using AutoSched Accelerated Processing. Consultants from Brooks Planning and Logistics Solutions and engineers at International SEMATECH then validated the model during an 18-month period. This validation included benchmarking against previous model results to validate model outputs and examining the intended logic by running the model with a variety of input settings and checking to see if the output was reasonable. The interactive debugger available in AutoMod was also used to trace and verify the logic followed by lots traveling through the simulated factory modeling software.

7 STATISTICAL CONSIDERATIONS

The experiment results are averages obtained in a steady-state analysis. The stochastic inputs to the model are tool downtimes and preventive maintenance of the tools. Because of these inputs, and the intrinsic variability of re-entrant manufacturing, the statistical sensitivity of the system to changing the number of load ports was examined. Using a batch means approach to obtain averages for the results of the simulation experiments, all results examined are significant for a 90% confidence interval.

8 MODELING METHODOLOGY

Each of the four models were simulated with a minimum number of two load ports on all tools. Data was collected from the results of these model runs. The four models were then executed multiple times while reducing load ports on metrology tools from two load ports to one while keeping the model stable. As metrology tools reduce their capacity and the model reaches stages of instability, reduction in load ports ceases. Models are considered unstable when WIP levels begin to increase over time. All models became unstable at varying points while load ports were reduced. Metrology in this report is limited to equipment used for measuring film thickness, measuring critical dimensions and measuring overlay. Each of these tool types are subdivided into front-end-of-line and back-end-of-line equipment and are distributed throughout the factory. Comparisons of results were then made looking at statistics for equipment like WIP levels, cycle time, completed lots, delivery times, and waiting for transportation times. Although cost is considered as a justification in adding or deleting load ports, cost was not contemplated or quantified. Table 1 describes the number of pieces of equipment that contain one load port in each of the models.

Table 1: Number of Metrology Tools with One Load Port

	CD	Film	Overlay	Total
Slow Conveyor	14	3	7	24
Fast Conveyor	19	9	10	38
Through Stocker	19	9	10	38
Point-to-Point	11	6	10	27
# of Tools in Population	19	10	10	39

9 RESULTS AND CONCLUSIONS

The overall comparison and high level results indicate wafer output is higher in the models when maximum number of load ports are maintained. On the average, twenty-nine more lots were completed (excluding Through Stocker model) in the factories over the 325-day period. Cycle time increased on the average of 6.4% with the fast conveyor having the highest percentage increase in cycle time of 10% and the Through Stocker model increasing only 2%. (Refer to Table 2a and 2b)

Table 2a: Standard Two Load Port Configuration

	Average Equipment Idle Time	Average Metrology Idle Time	Average Litho Idle Time	Completed Lots	Factory Cycle Time (days)	Factory Wip
Conveyor (slow)	23.73%	15.24%	10.06%	8,807	17.2	465
Conveyor (fast)	21.11	18.22	9.99	8,837	16.47	445
Through Stocker	25.42	22.14	9.99	8,795	17.15	463
Point-to_Point	25.24	21.93	9.83	8,829	15.88	430

Table 2b: Reduced Metrology Load Port Configuration

	Average Equipment Idle Time	Average Metrology Idle Time	Average Litho Idle Time	Completed Lots	Factory Cycle Time (days)	Factory Wip
Conveyor (slow)	22.6%	7.4%	9.85%	8,776	18.8	508
Conveyor (fast)	23.6	9.7	9.97	8,809	18.34	496
Through Stocker	24.95	15.96	10.02	8,821	17.51	474
Point-to-Point	24.3	16.38	9.74	8,801	16.6	447

When reviewing equipment average idle time, total equipment idle time stays roughly the same. The two-load port configuration has slightly more idle time of 24.76% compared to the one load port configuration for metrology tools with a value of 23.86%. It is an intuitive conclusion that the extra tool capacity given by the additional load port results in more idle time and is indirectly related to reducing time waiting for material to be delivered.

The methodology used in this analysis, to reduce load ports on an iterative basis, resulted in metrology equipment becoming less idle. At first glance, this seems counter intuitive given distances to transport wafers can be lengthy. In addition, with only one load port, metrology equipment looses it's buffering capability. Results of metrology idle time are the most significant observation from this modeling analysis. One would think that this should increase the idle time on one load port configured equipment because lots would have to travel from potentially many locations to be processed once the metrology tool in question would become available. The travel time caused by this phenomenon would increase idle time. To explain, of all equipment states, percentages for setup, processing, preventive maintenance, down time, and waiting for reticles to arrive are relatively constant between all 8 models in the two groups of models. However, WTTRAN% (waiting for transportation to arrive to transport lots), TRAN% (the travel time once the lot is picked up by the material handling system), and IDLE% fluctuate based upon changing model conditions. The total of these three variable non-processing times sum to ~ 27% and can be considered as total idle time. In the case of the Through Stocker model, idle time decreases from 22% to 16%. The latter represents the one load port configuration. This is caused by lots having to search for available metrology equipment, which may not always be in the current bay where the upstream process step occurred. Metrology seeking lots stay in the current bay for five minutes waiting for the nearest metrology tool to become available. After that time has expired, the lot that is seeking metrology for the downstream step will travel at times to the other side of the factory for the next available tool. Overall, metrology idle time as referred to in Table 3 decreased an average of 38% in the four models.

Table 3: Metrology Equipment Statistics

Two Load Port Data

Model	WTTRAN%	TRAN %	IDLE%
Conveyor (slow)	1.016	9.9	15.94
Conveyor (fast)	1.63	5.8	18.22
Through Stocker	1.8	2.5	22.14
Point-to-Point	1.62	3.01	21.93

Reduced Load Port Data

Model	WTTRAN%	TRAN %	IDLE%
Conveyor (slow)	0.78	18.4	7.4
Conveyor (fast)	1.3	16.5	9.7
Through Stocker	0.138	10.57	15.96
Point-to-Point	5.45	4.8	16.4

Although idle time has decreased, transportation time has increased by an average of approximately 1.6X. This travel time to find metrology equipment is strongly influenced by the speed of the transport system. In the case of the "Slow Conveyor", which appears to be the model that had the lowest transport capacity, only 62% (24 of 39) of metrology equipment could be reduced to one load port. In contrast, the "Fast Conveyor and the Through Stocker models had 38 of 39 metrology tools converted to one load port. In the Point-to-Point model, twelve of the thirty-nine tools remained with two load ports. The explanation for this is that the dispatching strategy within this model requires the lot to remain on the load port after processing completes at the current tool until the lot has an available downstream tool or until the current tool needs capacity to process the next lot.

The overall benefit from this study demonstrates that when AMH systems having similar functionality as modeled here, a factory can operate where some, but not all metrology equipment processes with one load port. As a result of the analysis of our simulations, the output indicates that additional load ports were not always needed to have a stable factory. Hence, the purchase cost of load ports and the footprint could be avoided. However, factories utilizing the two load port configuration on all metrology equipment would increase the capacity of their factory, providing additional time to measure more sites and potentially increase the yield of their factory.

The increased amount of FOUPs on the AMH system can be an issue. Today's factories are most certainly more congested with WIP than our specific models indicate. The material handling systems' slight increase of congestion to 6% was due to the added travel time and a significant increase in stocker usage. For some bays, this could be a justification for having the most utilized metrology tools equipped with two load ports. The models do show an increase in stocker usage for the Through Stocker and Point-to-Point vehicle models, which would be an indicator for increased travel frequency on the transport system. Less usage of stockers is seen in the conveyor models which use the conveyor sections as their primary storage and only use stockers once the conveyor has reached a stated capacity.

Average bottleneck queue lengths were monitored as modeling progressed. Lithography equipment for the most part remained the bottleneck and queue lengths increased primarily in the conveyor models by roughly 6X where metrology equipment became the bottleneck. The slower transport speed in these models is the main factor attributing to this result. However, with the two-load port configuration, conveyor models exhibited queue lengths comparable to that of the vehicle models.

Our findings can give factory managers an idea of the impact of metrology equipment and some alternatives to how their factory layout is conceived. This study also allows for the awareness of either purchasing additional metrology equipment or purchasing less metrology tools with one additional load port. Admittedly, the equipment layout used in these current models may not be considered optimal. And, an adjusted layout may provide more favorable results in some scenarios. A fab manager may decide that the purchase of equipment with dual load ports is considered cost effective in order to ship 29 additional 25-wafer lots in an eleven-month period. Since cost of load ports were not investigated and the value of processed wafers were not considered for this study, the authors offer no opinion on economic tradeoffs.

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