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CAPACITY ANALYSIS OF AUTOMATED MATERIAL HANDLING SYSTEMS IN SEMICONDUCTOR FABS

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ABSTRACT

A critical aspect of semiconductor manufacturing is the design and analysis of material handling and production control polices to optimize fab performance. As wafer sizes have increased, semiconductor fabs have moved toward the use of automated material handling systems (AMHS). However, the behavior of AMHS and the effects of AMHS on fab productivity is not well understood. This research involves the development of a design and analysis methodology for evaluating the throughput capacity of AMHS. A set of simulation experiments is used to evaluate the throughput capacity of an AMHS and the effects on fab performance measures. The analysis uses SEMATECH fab data for full semiconductor fabs to evaluate the AMHS throughput capacity.

1 INTRODUCTION

The semiconductor industry is swift moving and involves ever-changing technology, resulting in short life cycles for semiconductor products. In order to stay competitive, manufacturers must be able to quickly adapt to produce new products, and they must achieve a high level of productivity. Today, semiconductor manufacturing commonly requires over 400 processing steps involving 100 or more different tools with routings involving a large amount of reentrant flow (revisiting the same sequence of machine for each masking layer). Furthermore, 300mm semiconductor fabrication plants are as large at 3 football fields. Consequently, a critical aspect of semiconductor manufacturing is material handling.

As semiconductor manufacturers move to the use of 300mm wafers, the issue of material handling within the fab has become an increasingly important issue. Due to the size and weight of the 300mm wafer lots, people can no longer move lots between operations without risk of injury. Consequently, automated material handling systems (AMHS) are being implemented in 300mm fabs. One common AMHS configuration is the interbay/intrabay AMHS (See Figure 1) where a type of rail system is used to transfer wafer lots among tools within each bay, and a main intrabay system runs down the center of the facility to transfer wafer lots between bays. Stockers placed at the end of the bays are used for work-in-process storage and are used as an interface between the intrabay and interbay material handling systems (Inoue 2002).

Due to the complexity of the production process for semiconductors and the need for AMHS, research in the area of AMHS is critical to the achieving high levels of productivity and high levels of performance and on-time delivery for semiconductor manufacturers. In the research needs document for Semiconductor Factory and Supply Chain Operations, the National Science Foundation (NSF), International SEMATECH (ISMT), and the Semiconductor Research Corporation (SRC) state, "Realizing the potential of Moore's Law requires taking full advantage of device feature size reductions, yield improvement to near 100%, wafer size increases, and manufacturing productivity improvements. This in turn requires a factory that can fully integrate the production equipment and systems needed to efficiently produce the right products in the right volumes on schedule" (NSF/SRC 2004). Consequently, the study of AMHS in semiconductor manufacturing will be the focus of this paper.

2 OBJECTIVES

The main objective of this research is to develop a methodology for evaluating the throughput capacity of AMHS in semiconductor fabs. Furthermore, this research is intended to evaluate the effect of the AMHS on fab performance measures including throughput and cycle time. Based on this research, we plan to design and conduct an experiment to evaluate the AMHS factors that significantly affect fab productivity and performance which could lead to alternative AMHS designs.

3 RELATED WORK

Due to the complex nature of semiconductor fabrication, research with regard to improving productivity and fab performance is generally conducted utilizing simulation. Simulation allows for the investigation of many alternative system configurations without disrupting fab production. In particular, simulation studies have been conducted to analyze alternative AMHS in semiconductor fabs. Lin et al. (2003) utilize simulation to analyze a connecting transport module for an AMHS in a simplified 300mm wafer fab. Campbell et al. (1999) present a descriptive paper on a simulation model of a 300mm fabrication line at IBM which includes an AMHS. Mackulak and Savory (2001) present a simulation experiment that focuses on centralized versus distributed storage in an intrabay AMHS. Papronty et al. (2000) conduct a simulation experiment to compare a continuous flow (conveyor) system to an overhead monorail AMHS for semiconductor fabs. Finally, Murray et al. (2000) present a simulation based cost model for interbay material handling.

In addition to AMSH, simulation has been used to study production control aspects of semiconductor fabs including dispatching rules, order release, and rework strategies. Bahaji and Kuhl (2004) present a review of dispatching rules and present a full factorial experiment for comparing alternative combinations of order release and dispatching rules in semiconductor fabs. Kuhl and Laubisch (2004) develop rework strategies and conduct a simulation experiment to evaluate alternative combinations of rework strategies and dispatching rules for semiconductor fabs. In addition, Kuhl et al. (2004) conduct a simulation study to investigate the productivity of research fabs. Through this work, we have gained significant experience for modeling and analyzing semiconductor fabs and developing alternative production strategies for improving fab productivity and performance.

4 RESEARCH METHODOLOGY

The main activity during this project is to study AMHS systems in semiconductor fabs. In particular, we develop a methodology for evaluating the throughput capacity of AMHS in semiconductor fabs; and then to design and conduct an experiment to evaluate the AMHS factors that significantly affect fab productivity and performance. The first step in accomplishing these goals is to design and develop simulation methods to integrate AMHS and flexible control logic with full fab simulation models. Although there has been some research on the simulation of AMHS (Mackulak and Savory 2001, Paprotny et. al 2000, Hunter and Humphreys 2004, Campbell et. al 1999), these studies focus on specific applications/configurations or utilize oversimplified fab configurations. In this research, we develop a general modeling methodology for modeling AMHS the can be integrated into realistic simulation models of semiconductor fabs. Consequently, the methods and the experimentation that follow are conducted using actual fab data sets available through SEMATECH for the purpose of conducting this type of research.

To develop these simulation methods, we will utilize AutoSched and AutoMod which are two commercially available simulation packages that are used by many of the major semiconductor manufacturers to simulate their fabrication facilities. AutoSched is software specifically designed for modeling the operations, routings, and scheduling associated with semiconductor manufacturing. AutoMod is more general purpose simulation software that can be used to model material handling systems. These software packages have the ability to be linked to model both the operations and the material handling system in a single simulation model. In addition, these software packages provide facilities for customization. Consequently, our aim will be to customize a linked AutoSched/AutoMod model that will be capable of representing and behaving like an AMHS in a fully functional fab.

Once the simulation capabilities have been developed, our aim is to develop a method for evaluating the throughput capacity of AMHS in semiconductor fabs. Since there are many aspects of the fab (bottleneck tools, tool failures, etc.) that could limit the throughput of the system, the objective of this methodology will be to isolate the effects on throughput performance that are due to the AMHS and to identify the significant interaction effects on throughput between the AMHS and other factors. Knowing these effects, we intend to determine the maximum throughput capacity for the AMHS.

The next research objective of this project (currently underway) is to design and conduct an experiment to evaluate the AMHS factors that significantly affect fab productivity and performance. In particular, we plan to investigate factors such as interbay/intrabay movement, AMHS control logic, stocker (intermediate storage) quantity, and sizes of tool buffers. Furthermore, we plan to investigate the interaction of the AMHS control logic with the fab dispatching rules (queuing disciplines for determining the sequence in which wafer lots should be processed) and their effect on fab productivity..

5 SIMULATION MODEL

The simulation model was built in AutoSched AP using SEMATECH data set number 2 available from the Arizona State University data sets, which can be found at <`http://www.eas.asu.edu/~masmlab`>. These data sets are supplied anonymously from factories for research purposes. This specific dataset was for a factory with seven ASIC and memory products. The factory consisted only of back end operations including steps such as lithography, wet and dry etch, metal anneal, metal deposition, and cleaning among others. The factory has more products than those included in the set, but only data for seven was provided. Rework and yield data were provided. There were 97 different types of tools, approximately 10,000 wafer starts per month at full capacity, and an average of 26 process steps per mask layer.

After the model was built in AutoSched and was connected to AutoMod through the AMAP extension. An automated material handling system was then modeled in AutoMod

5.1 Assumptions

The following assumptions were made in the building of this model:

- Rework and scrap probability were listed in the data set both by lot and by wafer. Since AutoSched would only allow for one of them, only rework and scrap probability by wafer was modeled.
- A wafer travel time within the tool was listed in the dataset. In the model, this time was added into the processing time.
- While load and unload times were specified in the route for each product in the dataset, AutoSched required the load and unload times to be specified per tool. The average load and unload times per tool across all of the process routes were used.
- In the dataset, the maximum batch size at a step in the process route was often less wafers than the lot size. This caused the lots to be stop at that tool without being processed. When the simulation was run for 300 days, zero lots had completed processing. To resolve this problem, the minimum and maximum batch size units were changed from wafers to lots. If the maximum batch size was less than the lot size, the processing time was multiplied by the number of batches that fit in the lot. The new maximum batch size was always rounded up. If the maximum batch size was greater than the lot size the maximum batch size was divided by the lot size. The new maximum batch size was always rounded down. The processing time was left alone.
- The same setup rule and first in first out rank were used for tools to select a lot to process.
- No technicians were modeled.
- A factory layout and material handling system information were not included in the data set. The layout and AMHS that were modeled were not based on actual factory data, but follow commonly used layouts.

5.2 Factory Layout and AMHS

The factory layout and material handling system diagram are shown in Figure 1. The rectangles with curved edges show an overhead track for the material handling system. The rectangles with sharp edges show a stocker location where lots can be stored or transferred from between the interbay and intrabay material handling systems. The small dots represent tool locations and the small triangles represent both turntables and locations that a stocker can be entered and exited.

The factory is composed of a main isle with 10 bays on each side. Each bay is 75 ft. in length and contains between 8 and 18 tools. Ten stockers are present in the factory. Each stocker services two adjacent bays. The main isle consists of 5 overhead track loops with 4 turntables to transfer lots between them. Each track loop, whether it is in a bay or the main isle, is bi-directional and contains one vehicle which is restricted to only that loop. The vehicles are capable of carrying one lot at a time.

6 EXPERIMENT

As the purpose of the experiment was to determine the point at which the capacity of the material handling system effects the performance of the factory, it was important to ensure that the material handling system was the bottleneck of the factory. Otherwise, any degradation to throughput and cycle time with the increase of release rate might have been the result of tool bottlenecks and would have had little to do with the material handling system. To accomplish this, extra capacity was added to bottleneck tools until the addition of more tools did not have an affect on the performance.

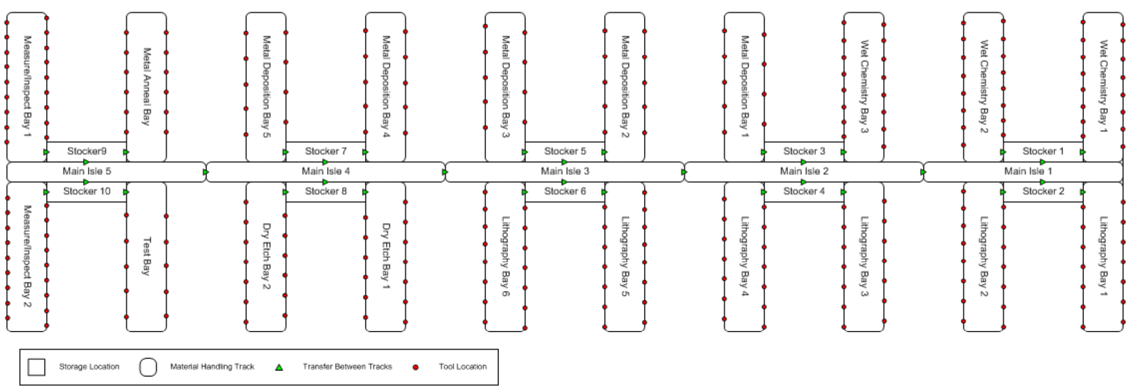

Figure 1: Factory and AMHS Layout

The model was run at release rates ranging from 50% - 150% of the rate reported in the data set of 10,000 wafers/month. Statistics on the average lot cycle time and vehicle utilization were collected.

7 RESULTS

The average cycle time of lots of all part types in the factory over the various release rates is shown in Figure 2. The average cycle time begins at 7.9 days per lot at a release rate of 5,000 wafers per month. It then rises slowly until a release rate between 13,000 and 14,000 wafers per month is reached, where the slope becomes much larger. This increase was due to the vehicle capacity since each stocker was not full at any time in the simulation.

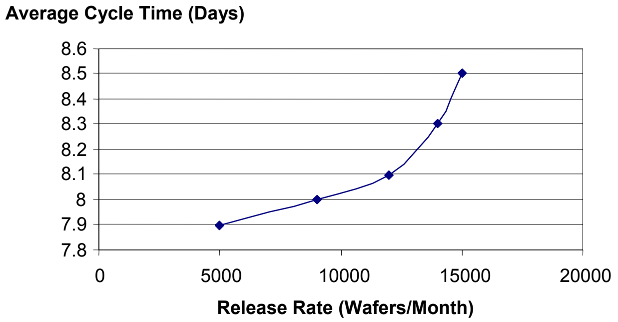

Figure 2: Average Lot Cycle Time vs. Release Rate

The utilization for the vehicle for Main Isle 3 was the AMHS vehicle with the highest utilization and was the limiting factor in the system. The utilization of this vehicle versus the release rates is shown in Figure 3.

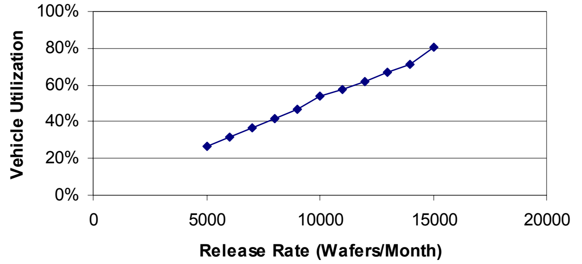

Figure 3: Utilization of the Highest Utilized AMHS Vehicle vs. Release Rate

Comparing Figure 2 and Figure 3, it can be seen that the increase in slope in average cycle time from Figure 2 corresponds to a vehicle utilization of about 70% for the highest utilized vehicle.

8 CONCLUSIONS

Using average cycle time as the performance indicator, this experiment showed that the performance of a factory can be diminished by the material handling system before the point at which any of the vehicles are 100% utilized. When designing a material handling system for a factory or considering increasing wafer release rates, the capacity of the material handling system should be considered in conjunction with performance factors from production and not only by itself. While this material handling system would have been capable of running with vehicles utilized at 80% or 90%, the negative effects to production may not have been acceptable.

9 FUTURE WORK

The next step in this study is to generalize this experiment by running it on different size factories with different types of material handling systems. The goal is to find an maximum range of AMHS vehicle utilization that can be applied to multiple factories without the need to run a similar experiment for each.

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