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Simulation Software for Semiconductor Photolithography Equipment: TrackSim

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반도체 포토 장비의 시뮬레이션 소프트웨어: TrackSim

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Abstract This paper describes the development of the TrackSim, which is a discrete event simulation tool for photolithography equipment of semiconductor industry. The TrackSim is focused on the accurate simulation model of the photolithography equipment and easy-to-use user interfaces. TrackSim provides 3D simulation environment for evaluating, validating, and scheduling the photolithography process. One of the major characteristics of TrackSim is in that it is developed based on Applied Materials' AutoMod, a discrete event simulation software broadly used in semiconductor industry. Accordingly, the photolithography model of TrackSim can be used to perform simulation connected with other simulation models built with AutoMod.

요 약 본 논문은 반도체 포토장비의 이산 이벤트 시뮬레이터인 TrackSim의 개발에 관한 것이다. TrackSim은 포토장비의 시뮬레이션 엔진과 사용하기 쉬운 사용자 환경을 포함하는 시뮬레이터로, 다양한 프로세스 모듈의 구성 및 운영 방법을 효율적으로 평가, 검증, 스케쥴링할 수 있는 3차원 시뮬레이션 환경을 제공한다. TrackSim은 반도체 산업에서 많이 사용되는 이산 사건 시뮬레이션 소프트웨어인 AutoMod를 기반으로 개발되어 시뮬레이션 신뢰성이 보장되며, AutoMod로 개발된 반도체 제조라인 시뮬레이션 모델 속에 함께 연동하여 사용이 가능하다는 특징이 있다.

Key Words : Simulator, Semiconductor Manufacturing, Photolithography Processes, Scheduling

1. Introduction

The purpose of this paper is to develop a discrete event simulation tool for photo- lithography equipment of semiconductor industry, named as TrackSim. A photolithography equipment consists of a cassette indexer, a track system and an exposure tool (or also called as a stepper). A track system is composed of 2-4 cells, each of which consists of a several process modules and a transfer module in each cell, and there is a buffer between cells. Recently, transfer robots are used for the transfer modules to increase the flexibility and efficiency in the track system [2]. The transfer robot moves a wafer from process module to process module in a cell, and from cell to cell. There is a cassette indexer at one end of the track system and the opposite end is linked to an exposure tool.

Figure 1 depicts the typical photolithography equipment with a robotic track system.

The photolithography process is usually bottleneck process in a wafer fab, and it is, therefore, challenging issue to improve performances of photolithography equipment. The performance indices of the photolithography equipment are throughput, cycle time, utilization of the process modules, utilization of the transfer robots,

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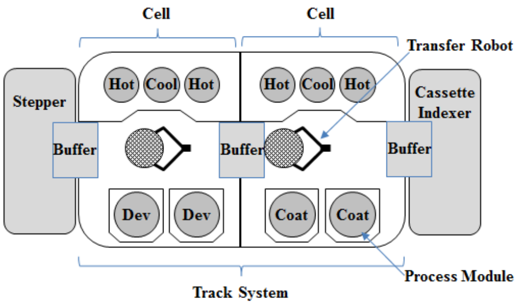
utilization of the exposure tool, and so forth. Among them, the throughput is one of the best well known performance measures of the track system [3, 6], and Akcalt et al. [1] insist that reduction of the cycle time in photolithography process reduce overall fab cycle time. However, it is very difficult to analyze the performance indices of photolithography equipment through mathematical approaches because of its complex process flow and near-infinite tool configuration possibilities. The simulation-based approach is promising method to predict and evaluate the performances of the photolithography equipment [4,5,9].



[Fig. 1] A simple layout of a typical photolithography equipment.

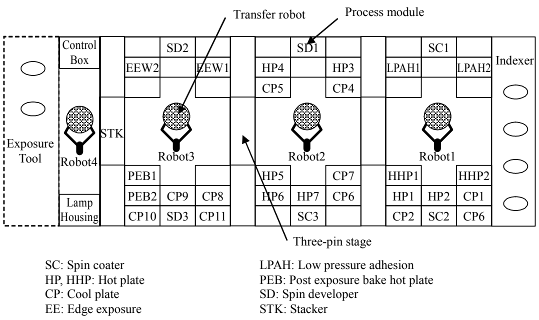
The main objectives of the TrackSim are as follows: first, the TrackSim can test and evaluate various attributes such as, product mix, process route, tool configuration, and scheduling rules. These attributes may be evaluated through simulation experiments with various combinations of them, then the best combination of the attributes can be determined. Second, the TrackSim is capable of validating if tool configuration is structurally efficient and selected scheduling rule is logically working. As mentioned before, dozens of process modules are classified and then located in each cell. The utilization of the transfer robots depends on the location of process modules in the track system. Accordingly, it is highly desired to locate process modules so that the tool configuration minimizes the frequencies of transferring a wafer from cell to cell. The processes of the wafers may not be completed due to deadlock that is an inherent problem in many resource allocation systems such as the track system. User can validate a tool configuration and a deadlock-free scheduling rule using the TrackSim. Finally, the scheduler of the TrackSim generates deadlock-free schedule. There are two kinds of scheduling rules for the photolithography equipment, that is, a sequence rule and an input release rule. The former is to select a wafer and an available process module for its next operation, and the latter is to determine the type of a wafer and the time to be released into the photolithography equipment. User can select the best performing combination of the sequence rule and the input release rule by comparing various scheduling rules through the TrackSim. The scheduler of the TrackSim includes a deadlock management algorithm to generate deadlock-free schedule proposed by Yoon and Lee [9,10].

The TrackSim uses the discrete event simulation engine and the 3D animation module of AutoMod distributed by Applied Materials, Inc. AutoMod is a discrete event simulation software broadly used in semiconductor industry. Therefore, the photolithography model of the TrackSim can be easily integrated with other simulation models developed using AutoMod.

2. Simulation Model

The photolithography process is a process of creating a pattern on a wafer, and is the most critical process in semiconductor fabrication. It has basic steps of coating, baking, cooling, exposing, and developing [11]. After photoresist is applied on a wafer in a spin coater, photoresist solvents are evaporated in the soft-baking step. An exposure tool transfers the pattern on the reticle or mask into the photoresist on the wafer by exposing light, which changes the structure and properties of photoresist on the wafer. The development step is to remove unpolymerized photoresist, and then photoresist solvents are additionally removed in the hard-baking step.

Figure 2 illustrates an example of photolithography equipment used for the simulation model of the TrackSim. The track system consists of three cells. It is assumed that the maximum number of process modules in each cell is sixteen. Three robots transfer wafers from process module to process module in each cell or from cell to cell, and one robot moves wafers from the track system to the exposure tool and vice versa. There is a three-pin stage buffer between cells and each stage can store one wafer at a time. A stacker (STK), which can store maximum 32 wafers at a time, is located between the track system and the exposure tool.

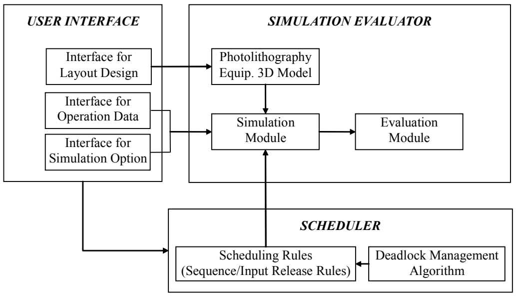


[Fig. 2] An example layout of photolithography equipment.

The simulation model of the TrackSim is focused on the photolithography equipment described as follows. The track system has multiple identical process modules to balance processing time and the transfer robots can skip unnecessary or failed process module. This increases flexibility in process routes of wafers. The photolithography equipment can produce multiple wafer types with different process routes, where the process route is assumed to have no re-entrance as typical photolithography process does.

3. Architecture of TrackSim

The TrackSim consists of a user interface, a simulation evaluator, and a scheduler. Figure 3 depicts the data flow in the TrackSim.



[Fig. 3] The architecture of TrackSim.

The user interface module consists of a layout design panel, an operation data input panel, and a simulation option panel. A user can easily configure simulation environment and parameters using these interface panels. The user can determine the location of process modules in the track system on the layout design panel. The operation data input panel is to enter the detail information of wafer processes, and the simulation option panel is to select simulation options such as scheduling rules. The user interface of TrackSim is developed using Microsoft Visual Basic, and the input data are transferred to the simulation evaluator and the scheduler using ActiveX.

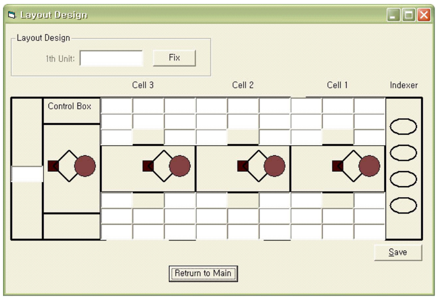
The simulation evaluator consists of the 3D model of the photolithography equipment, simulation module, and evaluation module. The photolithography equipment model is an accurate 3D model constructed using the tool configuration data transferred from the layout design panel. The 3D model is built using ACE (AutoSimulations' Creation Editor) and kinematics module provided in the AutoMod product suite. The simulation module performs simulation using the input data from the interface panels and the scheduling data from the scheduler. The simulation module uses the discrete event simulation engine provided by AutoMod. The evaluation module analyzes simulation results and then shows the various performance indices in text or graphical form. The evaluation module is implemented based on the statistical analysis tool of the AutoStat in the AutoMod.

The scheduler generates a deadlock-free schedule. The scheduler consists of scheduling rules and deadlock management algorithm proposed by Yoon and Lee [9,10]. The scheduling rules generate a schedule based on the operation data from the user interface. The scheduling rules of the TrackSim are applicable in dynamically changeable environment like machine breakdown, and the deadlock management algorithm helps to generate a deadlock-free schedule. The simulation evaluator performs simulations according to the schedule generated by the scheduler.

4. User Interface of TrackSim

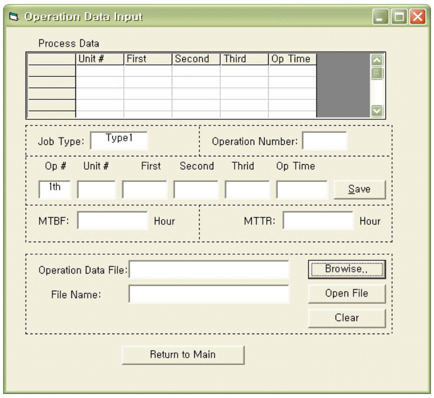
The TrackSim provides graphical and easy-to-use user interfaces to set up simulation environment and parameters. The TrackSim has three user interface panels, i.e., the layout design panel, the operation data input panel, and the simulation option panel.

Figure 4 shows the layout design panel, where a user can locate each process module in the track system. There are three cells in the track system, the left end of which is linked to the exposure tool. Each cell of the track system contains one transfer robot, and an additional transfer robot is located between the track system and the exposure tool. There are forty eight spaces to locate process modules in the track system and one space for the exposure tool. User can locate a process module into any one among these forty eight spaces. Some spaces may be set as empty ones if the total number of the process modules is less than forty eight. However, the user can not change the number of the cells and the transfer robots in this version of the TrackSim, which will be improved in the future work.

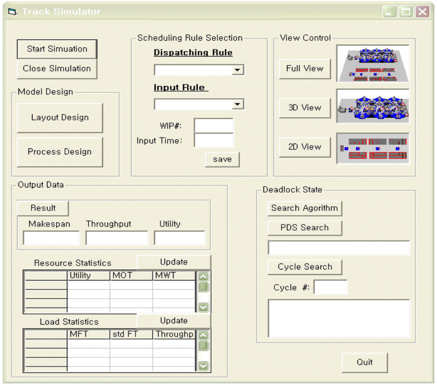


[Fig. 4] Layout design panel.

Figure 5 shows the operation data input panel, where a user can set up the simulation parameters of process routes. It should be noted that multiple wafer types can be processed simultaneously, and each operation can have routing flexibility. After designating the wafer type and the number of total operations, user can enter processing data for each operation step of the selected wafer type, i.e., the operation number, the number of identical process modules, the names of the process modules, and processing time. Then, the user can set the mean time between failure (MTBF) and mean time to repair (MTTR) for each operation. The operation data is saved as an ASCII file to be used for the next simulation.



[Fig. 5] Operation data input panel.



[Fig. 6] Simulation option panel.

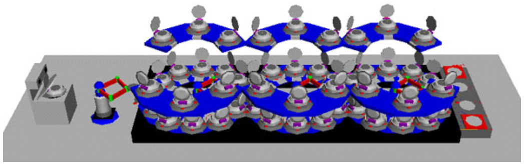
Figure 6 shows the simulation option panel, where a user can determine the scheduling rules and set some simulation options. The user can start and finish simulation experiment using the buttons in upper left corner of the panel, and open the layout design panel and the operation data input panel using the two buttons in model design group. The scheduling rule selection group is to select the combination of the sequence rule and the input release rule. User also set up the parameters concerned with the input release rule such as the number of work-in-process (WIP) and input interval time. The view control group is to select the view option during the simulation experiment. There are three types of view, i.e., 3D view, 2D view, and full view. The out data group is to show the preliminary simulation result such as makespan and throughput of the photolithography equipment, and the utilization of the process modules, and so forth. Finally, the deadlock state group is to find deadlock-prone process modules and then manage them.

The detail procedure of deadlock management algorithm can be found in [9].

5. Simulation Evaluator

The simulation evaluator of the TrackSim consists of the 3D model of the photolithography equipment, the simulation module, and the evaluation module.

The TrackSim provides an accurate 3D model for simulating the photolithography processes. The 3D model is built using the ACE and the kinematics module provided in the AutoMod product suite. ACE, an authoring tool to create 3D graphic model, is used to make the appearance of the entities of the photolithography equipment. The motion dynamics of the transfer robot is implemented using kinematics module. Figure 7 shows the developed 3D model of the photolithography equipment.



[Fig. 7] The 3D model of the photolithography equipment.

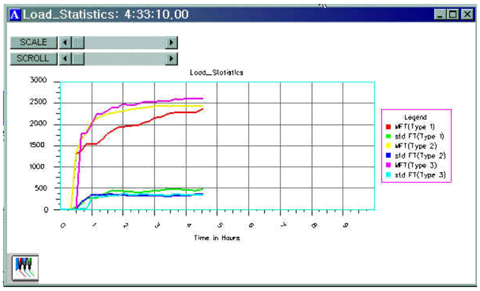
The simulation module performs a simulation using the input data from the user interface and the scheduling data from the scheduler. The basic structure of the simulation module follows that of the AutoMod, since the simulation module is constructed based on the AutoMod. There are three main components for the simulation module, i.e., process system, movement system, and logic source code. The process system includes general features for simulating photolithography processes. Main simulation processes are logically defined within the process system. The process system connects the movement systems to the logic of the operation processes in logic source code. The movement system is used to make the graphics model and kinematics of the transfer robot. The logic source code contains the logic for the simulation. The logic source code includes functions of the scheduling rules and the deadlock management algorithm.

The evaluation module offers evaluation function for various performance indices. It records the history of the time when an event occurs and the state in the data base system during the simulation. Therefore, user can evaluate the performance indices during or after the simulation.

The performance indices of TrackSim can be classified into three categories. The first category is the performance indices of the overall photolithography process. It contains the makespan and the throughput of the photolithography equipment. The makespan is the completion time of the last wafer and the throughput is the mean time to produce a wafer. The second category is the performance indices of the resources. It contains the utilization, the mean operation time (MOT), and the mean waiting time (MWT) of the process modules and the transfer robots. The third category is the performance indices of the wafers. It contains the mean cycle time (MCT) and the standard deviation of cycle time (Std. CT) of the wafers. The cycle time implies the interval time between the release and the completion of the wafer.

The important performance indices of the photolithography process are the throughput, the cycle time, and the utilization of the exposure tool. Thus, a user should select the sequence rule and the input release rule to maximize the throughput and to minimize the cycle time. It is also important to maximize the utilization of the exposure too, which is related with the tool configuration in the photolithography equipment. In other words, the user should determine the number of identical parallel process module to maximize the utilization of the exposure tool.

These performance indices can be reported in the simulation option panel of the user interface, or they can also be depicted as a graphical form. For instance, Figure 8 shows the performance graph of the wafers as simulation time flows. The lines in the graph are the mean cycle time and the standard deviation of the cycle time of the three wafer types.

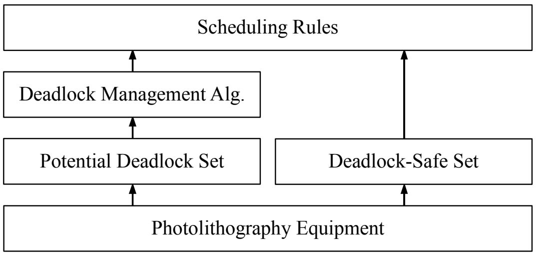


[Fig. 8] Performance graph for the wafers.

6. Scheduler

The scheduler of the photolithography equipment requires the high level of flexibility, and it should maximize the performances of the equipment such as the throughput and the cycle time. Thus, the scheduler should comprehend the capabilities of dealing with the breakdown of the process modules, generating a real-time schedule to improve productivity and utilization of the equipment, and managing the deadlock problem inherent in resource allocation systems with finite capacity.

The scheduler of the TrackSim uses the deadlock-free scheduling method developed by Yoon and Lee [9, 10]. The deadlock-free scheduling method includes the scheduling and deadlock management with consideration of breakdown of process modules. Figure 9 depicts the framework of the scheduler. The process modules in the photolithography equipment are logically classified into two sets, i.e., Potential Deadlock Set and Deadlock-Safe Set. The Potential Deadlock Set is the set of process modules prone to deadlock, and the Deadlock-Safe Set is the set of process modules free from deadlock. The deadlock management algorithm is applied only to the process modules in the Potential Deadlock Set. This approach significantly reduces the computation time to get deadlock-free schedule.



[Fig. 9] Framework of the scheduler.

7. Conclusion

The TrackSim is a discrete event simulation software developed for the photolithography process in semiconductor fabrication. The major characteristics of the TrackSim are as follows:

1) It offers an accurate simulation model of the photolithography equipment and easy-to-use user interfaces
2) It has the advanced scheduler that generates a deadlock-free schedule in spite of machine breakdowns.
3) It is developed using the validated commercial simulation software, AutoMod, that is broadly used in the semiconductor industry.
4) This approach has an advantage of reducing the endeavor to validate simulation models of new prototypes.
5) The simulation model of the TrackSim can be simulated together with other entities of semiconductor fab built using AutoMod.

Although the simulation model used for the TrackSim is a typical photolithography equipment model, it has the limitation that it can not change the number of cells and the transfer robot configurations. Thus, it is needed to improve the flexibility of the simulation model in the next version of the TrackSim. Besides, the future work will include the development of the more effective scheduling methods for the photolithography equipment and the optimization module to optimize the simulation parameters.

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