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Scheduling approach for a wafer fab with re-entrant flows and photo dedication constraints

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Abstract: In this research, we consider a scheduling problem for a wafer fab with dedication constraints of photolithography equipments. In a fab, wafer lots have to visit the serial operations (clean, diffusion, photolithography, etch and so on) to construct multi ($L \geq 2$) layers of semiconductor chips. Therefore, there are re-entrant wafer lots (j-th pass lot, $2 \leq j \leq L$) in a fab. Then, the re-entrant lots have to be operated in the photolithography equipments that the lot (first-pass lot) was operated in the first flow, which is called as dedication constraint. For the exact circuit alignments among layers of a wafer, the dedication constraint of photolithography equipment is very important, and we fulfill the dedication constraint of photolithography equipment. In this paper, we approach the concepts of heuristic algorithms considering the dedication load balance, and the objective function of this scheduling problem can be represented as minimizing the total flow time and so on.

Keywords: Photolithography, Fab, Dedication Constraint, Re-entrant Flows, Heuristic, Total Flowtime

I. INTRODUCTION

The wafer, which is a unit of semiconductor production, passes through hundreds of production processes using the LSIC (Large Scale Integrated Circuit) method, which is one of the typical production methods, and the circuit is directly connected to each layer to complete the final product [1]. In addition, the semiconductor manufacturing line (FAB) has a long process time and various process special restrictions and characteristics, therefore, the complexity of production management is very high compared to other manufacturing lines. Due to the complexity of production management, there are existing studies on the production and operation of semiconductor fabs as follows.

Choi and Kim [2, 3, 4] suggested some heuristics that can minimize the total tardiness and makes pan on the process with re-entrant flows of lots and for the same problems, branch and bound algorithms were developed by Choi [5]. One wafer lot is a collection of wafers and usually consists of 25 wafers and all wafers in one wafer lot must be transported together and processed together in a random facility. In other words, a lot is both a logistic movement unit and a process unit. Sung and Choung [6] presented an efficient batch methodology of lots to increase productivity in furnace equipment with a batch process in semiconductor fab. Also, a study on various lot release rules in semiconductor fab [7, 8] and a study on the schedule planning for the same kind of separate facility group [8, 9, 10,] were also performed.

In addition, the photo process, which is generally known as the most expensive equipment among the equipments of various processes, is naturally classified as a bottleneck process of fab, therefore, efficient scheduling in the photo process is very important. There are already many studies on scheduling for the photo process, but studies on scheduling considering dedication constraints, which are the main issues of photo equipment, are insufficient.

The reason for the existence of dedication constraints for photo equipment is that fab undergoes the same photo process several times in the process of integrating products, and even photo equipment belonging to the same equipment group (same type), exposure work that requires high precision is photo equipment. There may be a difference in quality in the minute difference in the angle of the reticle and the alignment of the wiring between the layers, so once the process is performed in an arbitrary photo equipment to configure the first layer, the re-entrant lots constitute the next layers. In order to do this, the photo process can be performed only on the equipment that has performed the first layer of the additional photo process [1]. That is, the lot that has completed the first photo process is re-inserted for multi-layer configuration, and the re-entrant lot is dedicated to the photo equipment where the first process was performed.

The important point when establishing schedule management in a fab with dedication constraints, which is a bottleneck process and re-entrant flow for multi-layer configuration, is to establish a schedule so that the loads of photo equipments can be well distributed. For example, if photo equipment A and B are available (Idle) and there is a lot (a first-pass lot that does not have dedication restriction) to select the equipment for the first photo process, we have to consider load balancing of photo equipments in later. For this purpose, it is necessary to allocate to the equipment with a small number of (Re-entrant and dedicated) lots that have already undergone the first photo process between A and B equipments to minimize the situation (that is, re-entrant and dedicated lots are crowded with certain photo equipment). In addition, the purpose of this scheduling problem is to minimize the total flowtime of lots (the total work flow time). The reason is that the actual semiconductor manufacturing line lacks buffers (Stocker and Shelf) to store stocks (lots), therefore, it is an important issue to minimize the time spent in the factory or in the buffer by completing the process as soon as possible. This is actually managed as KPIs in the fab [5].

This paper is organized as follows. Chapter 2 defines the scheduling problems considered in this study. Chapter 3 shows the direction of the heuristic algorithm to be developed for the scheduling problem dealt with in this study and the scheduling algorithm used in actual industrial sites. In the last chapter, the summary of this study and the direction of future research are described briefly.

II. PROBLEM DESCRIPTION

This study deals with the scheduling problem to minimize the total flowtime of lots, where there are dedication constraints and reloading of photo equipment. That is, under consideration of the characteristics of the above photo equipment, some approach of methodologies for the photo equipment (process) and simple methodology for other processes (that is, equipment such as etching, cleaning, diffusion and so on) are suggested.

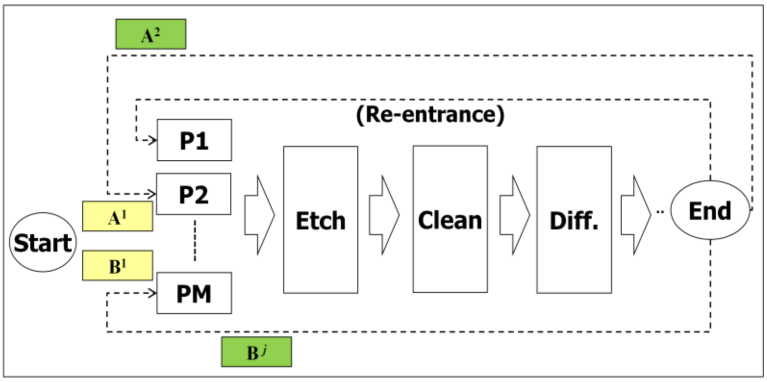

Fig.1 Re-entrant Flows and Photo Dedication constraints of lot in Mini-Fab

As described above, the wafer lots are formed as a layer by sequentially going through the above processes, and the semiconductor chip is composed of multi-layers, therefore, multi-layers are formed as shown in Fig.1, that is, there is a re-entrant flow. There are various processes, however, in this study, for the object of the scheduling problem, mini-fab consisting of photo, etching, cleaning, and diffusion, which are recognized as major processes among various processes, is considered as shown in Fig.1.

The following are terms and symbols to be used in this study.

I set of lots to be scheduled
M set of all facilities
P set of all photo facilities
E set of all etch facilities
W set of all clean(wet) facilities
D set of all diffusion facilities
i index for lot i (i=1, 2, ..., $|I|$)
p index for photo equipment p (p=1, 2, ..., $|P|$)
$[i]$ number of layers for lot i (that is, lot i has to be re-entered $[i]$-1 times
i^l l-th entered lot i ($1 \le l \le [i]$)
$\boldsymbol{k}$ The equipment with the fastest available time
$\boldsymbol{t}$ available time of equipment $\boldsymbol{k}$
R_i ready (arrival) time of lot i at the photo process
C_i work completion time of lot i (time when all necessary layers are configured)
F_i C_i-R_i, flowtime of lot i

$\sum F_i$ objective function of this scheduling problem, total flowtime of lots

In other words, there is a dedication constraint that requires the process for the composition of the next layers in the photo equipment that was processed at the time of initial injection. For example, if lot *i* is operated at photo equipment 2, then the operations for configuring the next layers must be performed in photo equipment 2. Therefore, instead of allocating the lot waiting for the first layer to the photo equipment with a low load (WIP Level) at the moment, it is necessary to allocate it in consideration of the load of dedicated lots that will be re-entered and returned. In summary, this scheduling problem is based on the following assumptions.

(1) In the photo process, the number of target work, that is, the number of wafer lots, is determined by the production plan for each day or for each shift (8hr). Therefore, the scheduling target work is predetermined.
(2) Equipment is not broken and its maintenance is not performed.
(3) In the photo, etching, cleaning, and diffusion processes, we all have a plurality of identical equipment.
(4) In the actual fab, since the photo process is not the first process, each lot (without no-layer, i^1) has its own ready time at photo process.
(5) The order of the processes is photo → etching → cleaning → diffusion, that is, after completing the photo process for forming the last layer of the lot, and then etching → cleaning → diffusion, the lot is all completed.
(6) The purpose of this scheduling problem is to minimize the total flow time.

In this study, we present an approach of a heuristic algorithm that can provide a schedule within a short time under consideration of the complex scheduling reality of the semiconductor manufacturing line as stated in the next chapter.

III. APPROACH OF SCHEDULING METHODOLOGY

The list scheduling methodology using dispatching rules that can be easily implemented in the actual manufacturing site selects the highest priority among those waiting in front of the equipment when an arbitrary equipment becomes available. In general, the priority of waiting lots is determined by a dispatching rule developed in advance [11]. In general, such list scheduling methodology is driven at a point in time (*t*) when there is a waiting lot when a certain equipment is idle [5]. In this study, we intend to modify and develop the basic list scheduling method as described above so that it can be applied to this scheduling problem.

***Existing Scheduling Algorithm* (*ESA*)**

First, we introduce the scheduling methodology that is actually applied in the leading wafer fab (semiconductor manufacturing line) in Korea. First of all, it selects equipment with the fastest available time and a lot to be scheduled on it. If tie occurs, select the equipment to be scheduled in the order of photo → etching → cleaning → diffusion process, and in the order of equipment number (index) when tie rate occurs even within the same process equipment. Among the lots waiting for the selected equipment, it is scheduled using the first-come-first-served (FCFS) rule.

In real fab, for photo, etching, cleaning, and diffusion, the FCFS rule is simply used to select the lot to be scheduled on the selected equipment. If a tie occurs, the priority was determined using SPT (Shortest Processing Time). If a tie occurs even with SPT, it is scheduled by selecting it at random (lot index). ESA is developed and implemented so that workers and engineers can easily understand it, and the following is the ESA's driving procedure, which is repeated until all tasks are completed.

Procedure of ESA

Step 1. Collect information on the current process completion time and location of the lot in process, equipment, dedication, process time, and the number of photo processes remaining in the lot.
Step 2. (Equipment selection) Select the equipment with the fastest available time while there is a lot (considering dedication constraints) among the *M*(considering dedication constraints) and the fastest available time is selected (the time point is set as *t*). If a tie occurs, select the equipment to be scheduled in the order of photo → etching → cleaning → diffusion process, and in the order of equipment number (index) when the tie rate occurs even within the same process facility.
Step 3. (Lot selection) If there are multiple lots allocable to the equipment selected in Step 2 at time *t*, select a lot (consider dedication restrictions) in the order of FCFS → lot number (INDEX).
Step 4. Schedule the selected lot(in Step 3) to the selected equipment(in Step 2).

Step 5. Update information on the current process completion time and location of the lot being processed, equipment, dedication, and the number of photo processes remaining in the lot.
Step 6. Repeat Step 2 → Step 5 until all work is completed.

***Suggested Scheduling Approach* (*SSA*)**

The scheduling methodology proposed in this study is similar to the general list scheduling method of selecting the lot to be scheduled after selecting an equipment by using the ESA in the field. In SSA, a module is added, and various dispatching rules were applied, not just FCFS, for the priority rules considering the dedication constraints of the photo process.

Initially, in Module 1, non-dedicated lots (lots that have not yet processed the photo process for the first layer) are determined on which equipment (each non-dedicated lot will process) by considering the load of the photo equipment. In other words, the waiting lots(i^1) for the photo process are allocated in advance according to a certain rule.

In this way, if i^1s are allocated in advance by a certain rule on which photo equipment to be proceed using Module 1, all lots become dedicated lots based on the photo process.

Next, the scheduling is performed in the same way as the ESA using the various dispatching rules of Module 2.

Procedure of SSA

Step 1. Collect information on the current process completion time and location of the lot in process, equipment, dedication, process time, and the number of photo processes remaining in the lot.
Step 2. By using the allocation rule of one of **Module 1**s, it allocates (determines) in advance according to a certain rule on which photo equipment the i1s will proceed to.
Step 3. (Equipment selection) Select i^1 the facility with the fastest available time while there is (waiting) a lot that can be processed in *M* among *M* (considering dedication constraints) (the point is set as *t*). If tie occurs, select the equipment to be scheduled in the order of photo → etching → cleaning → diffusion process, and in the order of facility number (index) when the tie rate occurs even within the same process facility.
Step 4. (Lot Selection) Select one of the various dispatching rules of **Module 2**s and select the lot to be scheduled according to that rule.
Step 5. Schedule the selected lot(in Step 4) to the selected equipment(in Step 3).
Step 6. Update information on the current process completion time and location of the lot being processed, equipment, dedication, and the number of photo processes remaining in the lot.
Step 7. Repeat Step 2 → Step 6 until all work is completed.

IV. CONCLUSION AND FUTURE RESEARCH

In this research, we consider a scheduling problem for a wafer fab with dedication constraints of photolithography machines. We approach the concepts of heuristic algorithms considering the dedication load balance, and the objective function of this scheduling problem can be represented as minimizing the total flowtime and so on. That is, we suggest the SSA for the scheduling problem. In SSA, we need the equipment selection rule **(Module 1)** and lot selection rule (Module 2). In future research, we will develop and test various rules to be used in Module 1 and Module 2, while completing SSA that can minimize total flowtime.

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