Abstract

Semiconductor device manufacturing business has shifted from high volume manufacturing to high-mix low-volume production. However, because the operation of production lines is conventional, production losses frequently occur. Therefore, we study for an optimization approach about lot progress schedule according to the delay in lot progress and the condition of production equipment. We propose a method which optimizes lot assignment, and it minimizes production loss. In order to realize it, we introduce a concept of grouping.

Keywords: Re-entrant flow shop, Grouping, High-mix low-volume production

1. INTRODUCTION

This paper aimed to examine a high efficient lot progress scheduling method in semiconductor device manufacturing characterized by the re-entrant flow of various processes (Taji, et al., 2004).

As the first approach, we introduce a grouping. The simple concept of grouping is to make a unit that is easy to handle in a large-scale and complex problem. For example, grouping means the unit of product or process, and so on. In semiconductor production scheduling, MES (Manufacturing Execution System) plans an outline of the lot progress scheduling. And lot assignment is carried out based on it. However, there is difference between the outline plan and the real lot assignment. In this paper, we proposed a method to optimize lot assignments using grouping.

In order to implement grouping, we introduced autonomous distributed element using a multi-agent. (Nishida, et al., 2010), (Monostori, et al., 2006). As such, the Real-Virtual Fusion Manufacturing System (RVF-MS) is proposed, which aims to adaptively and effectively deal with both external and internal fluctuations by realizing a fusion between real production shop floor (real system) and manufacturing model (virtual system) (Qian, et al., 2010). In this study, we defined equipment-agent and group-agent, and applied these as a system of base.

2. PROBLEMS AND DIFFICULTIES ON PRODUCTION SCHEDULING IN SEMICONDUCTOR DEVICE MANUFACTURING

- As specificity of the re-entrant flow (Fig.1), the same product lot is processed several times in the same equipment class. (Equipment class aims at a dotted line such as Deposition Process Equipment of Fig.1).

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**Fig. 1 Re-entrant flow shop model**

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• The number of product kinds which flows into a product line is increasing year by year. Hundreds of kinds of product lots flow on a product line simultaneously.
• In the same process, there are various processing procedures. They are classified based on the kind of the product. Equipment does not have only the capability corresponding to all the processes. Therefore, each product has to choose the specific production equipment. A relation is made between a product kind, specific one, or two or more equipment. (Fig. 2).

Fig. 2 Relation between product lot and equipment

• Various time loss factors occur at the operational phase. For example, unevenness of the processing time with individual production equipment, such as cleaning, sudden breakdown, interrupt request by express product lot (hot lot), etc. These factors being inevitable, a sophisticated re-schedule policy is necessary.
• The management of the factory handles these factors roughly from a statistics and make out the lot scheduling.
• The operation of lot scheduling in the factory is supported by simulation, but the adjustment is usually executed manually. However, as the amount of product lot is large and there is a complex factor, the adjustment is difficult. Therefore a solution to the problem is desired.

3. METHOD OF LOT ASSIGNMENT TO OPTIMIZE THE RESOURCES AND MATERIALS

3.1 Introduction of grouping

3.1.1 Concept of grouping

To improve the problem discussed in the previous chapter, we introduced a grouping. The concept of grouping is as follows:

• The elements with the same purpose are grouped together and it is treated as one group.

In other words, one group means a unit that is easy to handle. For example, a product lot certainly belongs to arbitrary product kinds, many lots exist in this group, and this is a group of a product kind. Equipment belongs to the equipment group that forms a group according to a processing kind.

Furthermore, it is expected that it becomes much easier to solve a problem by using the relations between groups.

3.1.2 Description of grouping

The standard method that is followed for lot assignments in factories is First in first out (FIFO) method (Fig. 3). It has several drawbacks as shown below:

• Adjustment of delivery dates of every type of product and the product quantity is difficult in case of lot assignments.
• The off-line set up becomes frequent, and the equipment operation rate decreases.

![Fig. 3 Scheduling with FIFO rule](image)

In this paper, we define the classification of groups as follows.

• product-group
• process-group
• product/process-group

In this case, if a group is formed for each type of product and it manages the production equipment as a resource, the product lot and production equipment can be treated as a line for each product-group (Fig. 4). In this way, production adjustment becomes easy because the target of the product is clear.

![Fig. 4 grouping for each type of product](image)
needed, process-group is to be used, and if detail of process2 is needed, Process2-group is to be used. In this way, an appropriate group is used by the situation.

![Diagram](image)

Fig. 5 Example of a cluster structure and a hierarchical structure of grouping.

### 3.1.3 Advantages in introduction of grouping

Grouping has the following advantages:

- A drop in the equipment operation rate caused by the off-line set up is avoided by production equipment being used by product-group.
- The arrival frequency of the product lot is estimated in a domain by using product-group. In order to improve productivity, group optimizes the number of resources and assigns the peak tendency in the processing order from a peak hour.
- Group manages the individual difference, time history, and cleaning work of the belonging resources (production equipment). This is the production equipment activity that is not recognized in MES (Manufacturing Execution System) and prevents loss by letting production schedule reflect this.
- Group manages only the necessary production equipment as a member. The unnecessary production equipment is utilized effectively, such as cleaning, spare to a problem occurrence, idle condition for energy-saving, etc.

### 3.1.4 Systematization of grouping by multi-agent.

The autonomous distributed systems by the multi-agent was built as the systematic method of implementation for grouping, in assigning agents to all production equipment (equipment-agent) and all groups (group-agent). Each equipment-agent has the duty of monitoring the production equipment and reporting the fluctuation to the group-agent. The group-agent can know the activity of the equipment, which is a subordinate, and in this way, works on the production improvement of the own group. Parallel processing by the autonomous distributed activities of these agents is expected. The detailed behavior of the agents is not the subject of this paper. The formation and cooperation of the groups, which applied multi-agent, are further work elements (Katoh, et al., 2001).

### 3.2 Scheduling model

In this paper, the target of production scheduling was our initial planning. We considered some models, which optimized lot assignment for each purpose depending on the situation. As the fundamental model in high-mix low-volume production, we defined the following:

**Model: Working fragment model**

Here, the use time of the production equipment attracts attention. Working fragment means the usable time is subdivided and it is named as a time slot. In high volume manufacturing, continuous use of the production equipment with the same product is appropriate. On the other hand, in high-mix low-volume production, flexible use of the production equipment with various products is necessary. Therefore, the product lot assignment to production equipment is based on a time slot through which every product gets the chance to use it. Overlapping of the use time for production equipment is avoided by using time slot.

### 3.3 Definition of Working fragment model

#### 3.3.1 Description

A product/process-group is formed for every product/process by predicting a necessary resource (production equipment) using the amount of product lot. As for the resource of the group, only minimum number of production equipment is secured. The remained production equipment is left as reserve force.

Furthermore, in this method, product/process-group gets the right to use a time slot unit of production equipment and product lot is assigned to it. However, the off-line set up occurs when production equipment is used by a different product fragmentedly. Thus, makespan minimization including the time of off-line set up is evaluated for an index of utilization.

#### 3.3.2 Scheduling procedure

1) The kind of product/process-group and static classification of the target resources are decided through product planning. (Fig. 6)

![Diagram](image)

Fig. 6 Static classification of product/process
2) The lot processing index (amount of product lot) in the process is roughly estimated during a target period of planning time. It is converted into timeslot.

3) The resource (production equipment) to meet an index of (2) is chosen among a classification of (1) in every process. This is decided as the issue of error minimization of required capability (the lot processing index is treated as required capability) and processing capability of the use resource. Furthermore, the product/process-group gets the right to use the timeslots of several production equipment. This is decided for the object of makespan minimization. The relations of production equipment and the product/process-group is dynamically classified each time and defined as operative group. (Fig.7)

![Diagram of equipment and timeslots](image)

**Fig. 7** Dynamic classification of product-process

4) For a timeslot unit of production equipment of group of (3), lots are assigned sequentially and it is an initial production schedule.

In procedure (3), the combination of timeslot and product/process may increase. Therefore, Combinational Auction (CA) is applied as the solution method. CA is the social contract based approach and its efficiency in the issue of combination problem is demonstrated (Kaihara, et al., 2009).

There are two problems in CA called Bid Determination Problem (BDP) and Winner Determination Problem (WDP). BDP determines the efficient placement of bids, which is submitted to the auctioneer. WDP determines the efficient allocation of items for bidders, to maximize the auctioneer's utility. (In this case, utility means the total rate of utilization.) These problems are difficult in large scale, so that using utility restriction in BDP to give an efficient and feasible solution space is effectiveness to solve the problem. (Qian, et al., 2010).

In this paper, the k-processes re-entrant flow shop problem is considered. CA is executed on each process.

### 3.3.4 Bid Determination Problem (BDP)

\[
\text{min} \quad \sum_{m=1}^{M} C_m x_m - \sum_{g=1}^{G} ZT_g
\]

Subject to

\[
ZT_g \leq \sum_{m=1}^{M} C_m x_m
\]

\[
x_m \in \{0,1\}
\]

\[
F_g^i = \max_{m \in S_g} \left( F_{t,m} + R_{t,m} \right)
\]

\[
F_g^i \leq U_g
\]

\[
F_g^i \leq FT
\]

(1) is defined as the issue of error minimization between target processing capability of all group and process capability of a production equipment targeted for use. In this way, minimum number of equipment is secured. (2) is constraint of Processing capability of production equipment m. It is necessary for all capability of production equipment to satisfy target capability of all groups. (3) is coefficient of determination. \(x_m = 1\) means the equipment m can be used for the bid.

The product/process-group determine the bids set of
timeslots of equipment which was decided (BDP) to satisfy their threshold of utilities \( U_g \), then submit bids set to the auctioneer. (4) shows the total finish time (make-span) for handling timeslots set \( S_g \). (5) represents the value of bid must satisfy the threshold \( U_g \) of resources (utility restriction).

As for the bid, all bids should be made to find the optimal solution. However, bid making may be difficult when combinations increase. In that case, it limits the number of the bids \( N_g \) and obtains a local solution by searching partially.

### 3.3.4 Winner Determination Problem (WDP)

\[
\min \sum_{g=1}^{G} \sum_{i=1}^{N_g} \sum_{m=1}^{M} \sum_{t=1}^{T} F_{g,i}^t x_{g,m,t}^i \quad (7)
\]

Subject to

\[
\sum_{i=1}^{N_g} x_{g,m,t}^i = 1 \quad (\forall g, \forall m, t \in S_g^i) \quad (8)
\]

\[
\sum_{g=1}^{G} \sum_{i=1}^{N_g} x_{g,m,t}^i \leq 1 \quad (\forall m, t \in S_g^i) \quad (9)
\]

\[
x_{g,m,t}^i \in \{0,1\} \quad (\forall m, t \in S_g^i) \quad (10)
\]

The auctioneer determines winners for groups (WDP). Local search in each process has been repeated to the limited times (LS).

In the case of a partial bid, a solution provided by winner decision is the partial most suitable solution. Therefore the trial of the LS time is carried out, and a solution is improved. The setting of the LS time can change by the situation and it is a work element.

(7) is the objective function to minimize the makespan. (8) indicates there must have one winner existing for timeslot \( t \) of equipment \( m \) in group \( g \), and (9) shows there is not more than one successful bid of winner’s all bids. (10) is the coefficient of determination. \( x_{g,m,t}^i = 1 \) means the bid \( N_g \) is the successful bid for timeslot \( t \) of equipment \( m \) in group \( g \).

### 4. Computational Experiments

#### 4.1 Conditions of experiments

In order to verify the effectiveness of the proposed method, computational experiments on re-entrant flow shop, which has three classifications of production equipment (Deposition, Photolithography, Etching) and five processes (process flow order is \#1 at Deposition \( \rightarrow \#2 \) at Photolithography \( \rightarrow \#3 \) at Etching \( \rightarrow \#4 \) at Photolithography \( \rightarrow \#5 \) at Etching), are executed. The system configuration and product planning are shown in Tables 1 and 2. We use the each product/process-group.

In system configuration, the processing capability of each production equipment is the same for every classification.

The dependence on product and materials movement time between processes is not considered. The time of off-line set up for production equipment is 0.5 h.

In production planning, there are three types of product. The processing priority is flat and the dependence on production equipment is not considered. Process required capability or the capability necessary for processing a product is the target process capability \( Z_{Tg} \) of product/process-group.

In this experiment, bids set of BDP is made by all bids. The threshold of utility \( U_g \) and repeat number of local search (LS) is not used.

<table>
<thead>
<tr>
<th>Table 1 System configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deposition</td>
</tr>
<tr>
<td>The number of equipment [number]</td>
</tr>
<tr>
<td>Target process</td>
</tr>
<tr>
<td>Processing capability [h]</td>
</tr>
</tbody>
</table>

<table>
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<tr>
<th>Table 2 Project planning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product A</td>
</tr>
<tr>
<td>The number of product lot [number]</td>
</tr>
<tr>
<td>Process required capability [h]</td>
</tr>
<tr>
<td>Process2</td>
</tr>
<tr>
<td>Process3</td>
</tr>
<tr>
<td>Process4</td>
</tr>
<tr>
<td>Process5</td>
</tr>
</tbody>
</table>

#### 4.2 Results of the experiment[s]

Tables 3 and 4 show the results of the experiments. Makespan of Table 3 has the same value of Process required capability of Table 2. This means that the problem of error minimization of required capability and processing capability is satisfied. By ten times of trials, the average of the calculation time of the solution was 3.49 sec.

Table 4 shows the result of time slot obtained by each group. Each group uses the same production equipment continuously, because if it uses production equipment fragmentedly, the time of off-line set up is added and makespan gets longer. This is the simple condition of the experiment, and yields appropriate results.

<table>
<thead>
<tr>
<th>Table 3 Experimental result 1 [makespan of each process.]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product A</td>
</tr>
<tr>
<td>make span [h]</td>
</tr>
<tr>
<td>Process2</td>
</tr>
<tr>
<td>Process3</td>
</tr>
<tr>
<td>Process4</td>
</tr>
<tr>
<td>Process5</td>
</tr>
</tbody>
</table>
Table 4 Experimental result 2 [Group.ID (A-C)]

<table>
<thead>
<tr>
<th>Timeslot No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process1: Deposition [equip.No]</td>
<td>B</td>
<td>A</td>
<td>C</td>
<td>B</td>
<td>A</td>
<td>C</td>
</tr>
<tr>
<td>Process5: Etching [equip.No]</td>
<td>B</td>
<td>A</td>
<td>A</td>
<td>C</td>
<td>C</td>
<td>C</td>
</tr>
</tbody>
</table>

5. CONCLUSION AND FUTURE WORKS

In this paper, we proposed a new methodology about optimal lot assignment with the grouping concept. After the formulation of the method, we verified several effectiveness of the proposed method by computational experiments. As the next step, we will introduce an extended approach about the production scheduling using the proposed grouping concept to:

- Challenge the experiments on the complicated conditions that gained parameters (the dependence on product, the materials movement time, etc.) and inspect the effectiveness of such case.
- Develop flexible scheduling method in operational phase. In this situation, the re-scheduling needs a study of more effective technique (Fukuta, et al., 2007).
- Define the behavior of multi-agent and group in operational phase. Flexibility and a cooperative system should be considered.

References


