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JOB SCHEDULING OF DIFFUSION FURNACES IN A SEMICONDUCTOR FAB

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ABSTRACT

Furnaces are commonly seen in the front-end to the middle portion of the semiconductor process flow. Job scheduling of furnaces needs to meet the daily production targets while adhering to job due dates and process constraints. The furnace scheduling problem belongs to a special class of flexible job-shop scheduling with complicated constraints including but not limited to batch processing, reentrance, and time-windows. This problem is NP-hard. The extremely large solution space prevents any straightforward application of optimization techniques. In this paper, several properties are identified to reduce the solution space based on a dynamic programming formulation. With the help of these properties, an efficient algorithm has been developed to find a good solution to this problem. The developed method has been implemented in practical production lines. Compared with existing methods, the developed algorithm gives a higher throughput rate and improves the scheduling efficiency.

1 INTRODUCTION

Semiconductor manufacturing plays an important role in the daily lives of modern society. In the wafer fabrication process, furnaces are commonly in the front-end to the middle portion of the process flow. A furnace is a parallel process batching machine in the diffusion area that has long process times. Due to its characteristics, such as batching, time windows, heterogeneous stations and reentrants, job scheduling at furnaces is commonly a challenging and time-consuming task in wafer fab operations. As a result, furnace scheduling is usually done by senior operators in most semiconductor fabs and through an ad-hoc manner. Since different operators may give priorities to different characteristics, even for the same situation, they may generate different schedules based on their experience and judgement.

The objective of furnace scheduling is to meet the assigned daily wafer throughput targets while adhering to job due dates and process constraints. To achieve this, jobs at furnaces are dispatched based on pre-determined sequences, which are usually arranged by operators every morning and adjusted dynamically throughout the day as needed. Since machines may have breakdowns and jobs may arrive differently than predicted, the pre-determined job sequence has to be adjusted whenever situations deviate from the original plan. Furthermore, among different furnaces, jobs may come back to the same group of furnaces via other furnaces within one day, and each furnace may have different capabilities (i.e., process various recipes) within the same tool group. Hence, even finding a feasible job processing sequence can be a challenging task, not to mention finding the optimal one.

In order to relieve the reliance on operators' experience and find a better schedule in a timely manner, this project was requested by our industry partners to develop an efficient scheduling algorithm for furnaces. Compared with the prior labor-intensive approach, the developed algorithm not only generates job schedules more efficiently, but also achieves higher customer service levels with more throughputs, while complying with complicated process constraints.

2 BACKGROUND

Knopp et al. (2017) defines the diffusion scheduling problem as a flexible job-shop scheduling problem with p-batching, reentrant flows, sequence-dependent setup times and release dates. The process at the diffusion area starts with the chemical cleaning of wet benches (or cleaners). After being cleaned, wafers are loaded into the furnaces and the processes of annealing or deposition are performed. As the process flows are different among products, wafers of different products may flow through different furnace groups with different reentrant frequencies. A job can visit the diffusion area (maybe different furnace groups) more than one time within a day. Due to quality concerns, some jobs have the schematic of the diffusion process time windows (or queue time constraints) between the cleaners and the furnaces (Wang et al. 2018). When time windows exist, the waiting time of wafers before being loaded into the furnaces is limited. Wafers exceeding the time window (usually a few hours) have to be reworked or scrapped.

To guide job dispatching, the schedule must indicate the start times of the batches at all tools and the specific jobs within each batch, while also satisfying the daily move target of each product and comply with all constraints. This scheduling problem falls into the category of flexible job-shop scheduling with job release times, machine dedications, reentrance, parallel batch processing, breakdowns and time-windows. The objective is to maximize the weighted move target by searching for the optimal production schedule. Since the state of a tool group changes dynamically, the schedule also has to be updated frequently within a day. On the other hand, there can be thousands of jobs waiting to be assigned to dozens of tools. The problem complexity is far beyond the small problems with optimal solutions in prior literature. Indeed, even meta-heuristics are reported to fail in solving large problems in practice (Mönch et al. 2011). To tackle this challenging problem, we first reduced the solution space by exploring the inherent structures of the problem through a dynamic programming formulation and then applied its insights to solve a real case using a genetic algorithm.

3 CONCLUSION

Due to parallel batching and long process times, furnace scheduling plays an important role in wafer fab operations. However, the large problem size and complexity limited the application of mathematic models effectively in practice. As a result, furnace scheduling heavily relied on the judgment and experience of operators in the past, which inevitably led to lower efficiency and productivity.

Based on the dynamic programming formulation, two sufficient conditions are derived. One gives instructions to form larger batch sizes and the other reduces the selection pool of jobs and tools for each batch. The proposed algorithm takes advantage of these inherent properties and achieves significant improvements in the problem instances of practical scales. The algorithm is able to decrease the violation of time windows and reduce the waiting times of jobs and the idle times of tools while increasing effective moves. It not only improves the scheduling quality but also relieves operators' workload with its highly sophisticated scheduling activity.

Although the algorithm can generate a good feasible schedule efficiently, we believe the solving time and solution quality can be further improved by finding more inherent properties through a deeper understanding of the system. Furthermore, scheduling algorithms for other machine groups with different configurations and requirements are left for future research.

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