Chapter 8
Real-Time Scheduling and Control of Single-Arm Cluster Tools with Residency Time Constraint and Activity Time Variation by Using Resource-Oriented Petri Nets

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ABSTRACT

In semiconductor manufacturing, when a wafer is processed, it requires unloading from its process module in a given time interval, otherwise it is scraped. This requirement is called wafer residency time constraints. Thus, it is crucial to schedule a cluster tool such that the wafer sojourn time in a process module is within a given time window to satisfy the wafer residency time constraints. Besides wafer residency time constraints, in a cluster tool, the activity time is subject to variation. The activity time variation can make a feasible schedule obtained under the assumption of deterministic activity times become infeasible. To solve this problem, it is important to reveal the wafer sojourn time fluctuations with bounded activity time variation. Such an issue is addressed in this chapter for single-arm cluster tools. A single-arm cluster tool is modeled by a resource-oriented Petri net to describe the wafer fabrication processes. Based on it, a real-time control policy is proposed such that it offsets the effect of the activity time variation as much as possible. Then, the wafer sojourn time delay in a process module is analyzed

DOI: 10.4018/978-1-4666-4034-4.ch008

and analytical expressions are derived to calculate the upper bound. With the help of the real-time control policy and wafer sojourn time delay analysis results, schedulability conditions and scheduling algorithms for an off-line schedule are presented in this chapter. The schedulability conditions can be analytically checked. If schedulable, an off-line schedule can be analytically found. The off-line schedule together with the real-time control policy forms the real-time schedule for the system. It is optimal in terms of cycle time minimization. Examples are given to show the application of the proposed approach.

1. INTRODUCTION

In semiconductor manufacturing, a cluster tool is widely used to process wafers one by one with single-wafer processing technology because it can achieve better quality control for processing large-sized wafers, such as 300mm ones and reduce the fabrication lead time. A cluster tool consists of several processing modules (PM), an aligner, a wafer handling robot, and two loadlocks for wafer cassette loading/unloading. In general, a cassette has 25 wafers with an identical recipe (Kim *et al*., 2003; and Lee and Park, 2005). Raw wafers are loaded into the system through a loadlock, visit one or more PMs in a pre-specified order (each wafer should stay in a PM for a minimum time in each step to get processed), and return to the loadlock where they come from (Wu *et al*., 2008a). By using such a tool, it can provide a flexible, reconfigurable, and efficient environment for semiconductor manufacturing (Bader *et al*., 1990; and Burggraaf, 1995), resulting in higher yield (Newboe, 1990), shorter cycle time (McNab, 1990; Newboe, 1990; and Singer, 1995), better utilization of space (Burggraaf, 1995; and Singer, 1995), and lower capital cost (Singer, 1995). For a cluster tool, the wafer handling robot can be a single or dual-arm one as shown in Figure 1 (a) and (b), respectively.

To effectively operate cluster tools, important effort has been done in modeling and performance evaluation of cluster tools (Venkatesh *et al*., 1997; Ding *et al*., 2006; Perkinson, *et al*., 1994 and 1996; Yi *et al*., 2008; Zuberek, 2001; Chan *et al*., 2011; and Wu and Zhou, 2010a and 2010b). With these models, it is found that, under the steady state, the operations of a cluster tool are divided into two different regions: transport and process-bound ones. In the former, the robot is always busy and the system cycle time is determined by the time for robot tasks, while in the latter, the robot has idle time and the processing times in PMs determine the cycle time. In a cluster tool, only after a wafer is loaded into a PM can the PM start its wafer processing. Thus, PM activities follow the robot tasks (Shin *et al*., 2001). Hence, it is very crucial to schedule robot tasks. With these properties, dispatching or priority rules are developed to schedule them (Venkatesh *et al*., 1997; and Jevtic, 1999). In a cluster tool, the robot moving time from one PM to another can be treated as a constant and are much shorter than the wafer processing time (Kim *et al*., 2003). Thus, backward scheduling is optimal for a single-arm cluster tool (Lee *et al*., 2004; and Lopez and Wood, 2003). However, these results are obtained based on the assumption that there is no limitation on how long a wafer can stay in a PM after being processed.

For some wafer fabrication processes, such as low pressure chemical-vapor deposition (LPCVD), there is a strict constraint on the wafer sojourn time in a PM (Kim *et al*., 2003; Lee and Park, 2005; Rostami *et al*., 2001; and Yoon and Lee, 2005). It is referred to as residency time constraint (Rostami *et al*., 2001). It means that a wafer should be unloaded from a PM within a limited time after it is processed, and otherwise, the wafer would be scrapped. Without immediate

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