Chapter 7
A Resource-Oriented Petri Net Approach to Scheduling and Control of Time-Constrained Cluster Tools in Semiconductor Fabrication

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ABSTRACT

Because of residency time constraints and activity time variation for cluster tools, it is very challenging to schedule them. This chapter addresses their real-time scheduling issues and conducts their schedulability analysis in considering residency time constraints and bounded activity time variation. A Petri Net (PN) model, called Resource-Oriented PN (ROPN) is developed to model them. Such formal models describe not only the behavior of both initial transient and steady state processes of cluster tools but also determine the robot activity sequence with robot waits included. They are very compact, independent of wafer flow pattern, and useful for discrete-event control. It is due to the proposed models that scheduling cluster tools are converted into determining robot wait times. A two-level operational architecture is proposed to include an off-line periodic schedule and real-time controller. The former determines when a wafer should be placed into a process module for processing, while the latter regulates robot wait times on-line in order to reduce the effect of activity time variation on wafer sojourn times in process modules. Therefore, the system can adapt to random activity time variation. Based on the PN model, real-time operational architecture, and real-time control policy, it analyzes the effect of activity time variation

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on wafer sojourn time delay at a process module and presents its upper bounds. The upper bounds are given in an analytical form and can be easily evaluated. Then, it derives schedulability conditions that are in closed form expressions. If schedulable, an algorithm is developed to obtain an off-line periodic schedule. This schedule together with the real-time control policy forms a real-time schedule. It is optimal in terms of cycle time and can be analytically computed, which represents significant advance in this area. Several examples are used to show the applications of the proposed approach.

1. INTRODUCTION

Two goals of semiconductor industry are: 1) better quality control of processing large-sized wafers such as 300mm ones; and 2) reduction of the wafer fabrication lead time. The industry has developed a single-wafer processing technology that processes wafers one by one at a process module (PM). To better fulfill the mentioned goals, it adopts more and more integrated manufacturing equipment such as cluster tools and track systems that integrate several PMs for different process steps with material handling robots. In such equipment, several single-wafer PMs for different process steps are combined into a single cluster tool with one or more wafer handling robots, and thereby, excessive wafer transporting efforts and waiting between PMs can be significantly reduced.

Cluster tools provide a flexible, reconfigurable, and efficient environment for semiconductor manufacturing (Bader *et al*., 1990; and Burggraaf, 1995). Each tool consists of a number of PMs, an aligner, a wafer handling robot, and a couple of loadlocks for wafer cassette loading as shown in Figure 1. Each cassette has about 25 wafers that often share an identical recipe. Raw wafers enter the system through a loadlock and visit one or more PMs in a specific order and return to the loadlock. Each wafer should stay in a PM for a minimum time in each visit to get processed. The robot unloads a wafer from a loadlock to PMs, and loads it back to the loadlock after its processing. The robot also handles a wafer's transportation among PMs. It can be single-armed as shown in Figure 1(a) or dual-armed in Figure 1(b). The latter has two blades pointing in opposite directions, each capable of carrying a wafer. The two blades are tightly coupled by construction, i.e., at any time only one of the two blades can pick or place a wafer from or into a module (Venkatesh *et al*., 1997).

Great effort has been made in modeling and performance evaluation of cluster tools (Perkinson *et al*., 1994; Perkinson *et al*., 1996; Venkatesh, 1997; Zuberek, 2001; and Ding *et al*., 2006). With these models, a periodic steady state schedule can be found. Their operations are divided into two different regions: transport- and process-bound. In the former, the robot is always busy and the period of the system is a function of robot task times. In the latter, the robot has idle time and the period is determined by the processing times in PMs. the robot moving times from one PM to another can be treated as a constant and are much shorter than the wafer processing times (Kim et al., 2003). As pointed out in (Shin et al., 2001), in cluster tools, PM activities follow the robot tasks. Hence, it is important to schedule the robot tasks. Dispatching or priority rules are developed to schedule them (Venkatesh *et al*., 1997; and Jevtic, 1999). There is a useful scheduling method for dual-arm cluster tools called swap, which is shown to be efficient (Venkatesh *et al*., 1997). Based on the swap method, an earliest start strategy is used to schedule the robot tasks for dual-arm cluster tools except for operations of unloading wafers from loadlocks (Shin *et al*., 2001). However, these methods are developed based on a questionable assumption that a wafer can stay in a PM for an unlimited time.

Since the modules are tightly coupled and no intermediate buffer exists between the modules,

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