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Fuzzy neural network-based rescheduling decision mechanism for semiconductor manufacturing

J. Zhang *, W. Qin, L.H. Wu, W.B. Zhai

School of Mechanical Engineering, Shanghai Jiao Tong University, 800 Dongchuan Road, Shanghai 200240, China

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ABSTRACT

Most semiconductor manufacturing systems (SMS) operate in a highly dynamic and unpredictable environment. The production rescheduling strategy addresses uncertainty and improves SMS performance. The rescheduling framework of SMS is presented as layered scheduling strategies with an optimization rescheduling decision mechanism. A fuzzy neural network (FNN) based rescheduling decision model is implemented which can rapidly choose an optimized rescheduling strategy to schedule the semiconductor wafer fabrication lines according to current system disturbances. The mapping between the input of FNN, such as disturbances, system state parameters, and the output of FNN, optimal rescheduling strategies, is constructed. An example of a semiconductor fabrication line in Shanghai is given. The experimental results demonstrate the effectiveness of proposed FNN-based rescheduling decision mechanism approach over the alternatives such as back-propagation neural network (BPNN) and multivariate regression (MR).

1. Introduction

Semiconductor manufacturing systems (SMS) are more complicated than conventional manufacturing systems in terms of technologies and manufacturing procedures. A mix of different process types (batch processes and single wafer processes), sequence dependent setup times, expensive equipment, and reentrant flows are typical for SMS [1]. Between 250 and 500 process steps on 50–120 different types of equipment are required to produce a chip of average complexity. Since the 1990s, the market of semiconductor fabrication has become increasingly global, dynamic and customer driven. An organization's competitive advantage depends more and more on its responsiveness in meeting market changes and opportunities, and in coping with unforeseen circumstances (i.e., machine breakdowns, rush orders, etc.) Thus, it is important to reduce inventories, decrease cycle time, and improve resource utilization. These goals call for optimization and scheduling approaches that optimize the allocation of scarce and expensive resources among competing activities [2]. Uzsoy et al. [3] provided an excellent review of scheduling research for SMS. SMS operates in uncertain dynamic environments, where disturbances include: machine failure, lot rework, and rush orders. Production rescheduling is an effective response to uncertainty created by the exterior business environment and the interior production conditions. When disturbances happen, the rescheduling strategy needs to be selected and carried out.

This paper is motivated by the problem of rescheduling semiconductor wafer fabrication lines, where the schedule solutions are easy to be infeasible due to dynamic and uncertain production environments. Existing approaches to rescheduling the semiconductor wafer fabrication system generally consist of a single strategy for special situations, which is not enough for the real-time and dynamic manufacturing environments. Therefore this paper focuses on an optimal rescheduling method and proposes a fuzzy neural network (FNN)-based rescheduling decision mechanism for SMS.

The paper is organized as follows. The next section gives a brief introduction to SMS and reviews literature about rescheduling. Section 3 describes the layered rescheduling framework of SMS. Section 4 constructs an optimization rescheduling decision mechanism based on FNN. Section 5 reports numerical experiments based on the data of a 6 inch SMS in Shanghai. The paper concludes in Section 6 with a discussion of the application of FNN-based rescheduling decision mechanism to SMS.

2. Literature review

The semiconductor manufacturing process can be broadly classified into three major stages: material preparation, wafer fabrication, and assembly and testing [4]. Wafer fabrication is the

* Corresponding author. Tel.: +86 21 34206292; fax: +86 21 34206292.
E-mail addresses: zhangjie@sjtu.edu.cn, zhangjiegu@gmail.com (J. Zhang).

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most complex stage. Multiple layers of integrated circuits are imprinted on the wafer surface. Wafer fabrication requires an enormous investment in facilities. The necessary machines are not duplicated in a fabrication line but are grouped by type. So, wafers repeatedly revisit the same machine type for processing at different layers. This process is called a re-entrant flow of wafers [5]. During wafer fabrication, quantities of wafers are grouped into a standard container, called a lot. The wafers in a lot are all the same type of product and travel as a unit among machines. This research focuses on the wafer fabrication process within the overall semiconductor manufacturing process.

Wafer fabrication operates in a dynamic and unpredictable environment. Production rescheduling presents an effective solution.

There has been much research on rescheduling in job shops and flow shops environments [6]. This research has mainly focused on heuristic algorithms, intelligent and simulation methods. The existence of a re-entrant flow differentiates production planning in SMS from traditional flow and job shop models. Many papers have explored SMS rescheduling in the recent decade. Cheng et al. [7,8] proposed an online rescheduling method of short-time schedules with message passing and a sorting rescheduling algorithm. This approach can revise the original schedule and accommodate schedule disturbances in less than 1 second. Huang and Chen [9] proposed an on-line rescheduling mechanism combined with the theory of constraints (TOC). Genetic algorithms (GA) have been used for searching dispatching rule sets with better performance. Experimental results showed that GA is effective at obtaining dispatching strategies. Kumar et al. [10] presented a novel scheme for rescheduling a semiconductor fabrication line. Rescheduling is done when machines breakdown and when the job queue length exceeds a threshold. Mason et al. [11] proposed three different rescheduling strategies (right-shift rescheduling, fixed sequence rescheduling and total rescheduling) for complex job shops such as wafer fabrication systems. Numerical experiments revealed the effectiveness of each strategy at maximizing on-time delivery performance. Tsai and Huang [12] studied a real-time scheduling and rescheduling system based on RFID (radio frequency identification) for fully automated fabs. The system had a rescheduling mechanism for machine breakdowns and bottleneck based on the dispatching rule sets proposed by the SVM (support vector machine) scheduler. Lee et al. [13] presented a Petri-net based rescheduling strategy to construct a mathematical programming model in order to reduce the impact of human errors and to ensure operational efficiency. The rescheduling model for batch chemical processes was represented by the token movements in a Petri net and the optimal schedule for semiconductor processes was determined accurately. Yugma et al. [14] proposed an efficient heuristic algorithm for solving a complex rescheduling problem in a diffusion area of a semiconductor plant. A constructive algorithm was designed and improvement procedures based on iterative sampling and simulated annealing (SA) were developed. The proposed approach to group lots in batches and to schedule these batches on machines is verified to be feasible and effective. Chuang et al. [15] studied a multi-station rescheduling problem with flexible capacity and loading balance. A mixed integer programming model was designed with the consideration of flexible capacity restriction to minimize wafer scrap and cycle time. Hung et al. [16] investigated the rescheduling problem of the photolithography area in semiconductor wafer fabrications. The objective is to find a schedule that minimizes the weighted sum of makespan, maximum tardiness, and total setup time. Three popular search algorithms: SA, GA, and tabu search (TS) are tested to solve the scheduling problem. The results show that TS performs the best and the performance of the sensitivity TS significantly surpasses that of the traditional approach.

The above SMS rescheduling methods consist of single strategies for special situations. Most SMS rescheduling strategies grew out of traditional job shop rescheduling methods. Within the last five years the investigated rescheduling problem in SMS became more and more complicated, various approaches such as Petri net, SA, GA and TS are utilized. However, SMS is more complex. It faces disruptive events every day. A single rescheduling strategy is not enough for the real-time dynamic manufacturing environment. An effective rescheduling strategy should choose rescheduling methodologies adaptively based on the current system disturbances. This paper formulates a layered rescheduling framework for SMS and proposes a rescheduling decision mechanism to adaptively and dynamically choose particular layered rescheduling approach.

The FNN approach is an effective methodology for selecting a scheduling strategy. FNN is also widely used in control, decision-making and prediction of discrete event manufacturing systems. Li et al. [17] used a fuzzy neural network approach to describe the relationship between the tool conditions and the monitoring features of a flexible manufacturing system. Zhou et al. [18] presented a fuzzy neural network approach for manufacturing process control. Chang et al. [19] created a FNN model of flow time estimation using simulated data generated from a foundry service company. Xu and Yan [20] used FNN to estimate the product design time. Experiments showed that the proposed method was feasible and effective. Chang et al. [21] used FNN to estimate the influence of the process recipe on wafer fabrication outcomes in SMS. Although FNN has appeared many times in the literature, it has not been applied to the SMS rescheduling problem.

A FNN-based rescheduling decision mechanism for SMS is presented in this paper. It solves the uncertainty problem, and expert knowledge is expressed in weighted values. The knowledge modeling of control rules becomes the evaluation of local weight values in the neural network. In this model, uncertainties about SMS state parameters, disturbance parameters and rescheduling strategies can be identified and analyzed. Further, the non-linear relationship between these three components can be set-up. As a result, this approach will select the layered rescheduling approach that yields rapid responsiveness and high productivity of the SMS in a turbulent market and fabrication environment.

3. Layered rescheduling framework of SMS

SMS operates in uncertain dynamic environments, where the main disturbances include machine failure, lot rework, rush orders and so on. When such unpredicted disturbances occur, rescheduling is required. However, considering the complexity of SMS, it is necessary to adopt different rescheduling strategy on basis of current system status and the impact of the disturbances to reduce the computing cost, and at the same time to ensure the stability and effectiveness of scheduling. Therefore in order to adaptively and dynamically reschedule the SMS for the unpredictable SMS environment, a layered rescheduling framework is constructed, as shown in Fig. 1.

Notice that there are three levels of rescheduling strategies in the framework, which are the rescheduling strategy in the system layer, machine group layer, and machine layer. The FNN-based optimal rescheduling decision mechanism is proposed to adaptively and dynamically choose the particular rescheduling strategy according to system's status and disturbances. The details of the layered rescheduling framework are described as following.

(1) Rescheduling strategy in machine layer. When the change of SMS's status or disturbances are of small impact[1] to the system,

[1] This impact is quantified in Section 4.2.1.