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Optimization of preventive maintenance strategies in a multipurpose batch plant: application to semiconductor manufacturing

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Abstract

This paper addresses the problem of preventive maintenance (PM) strategy optimization in a semiconductor manufacturing environment, with the objective of minimizing maintenance costs. The approach developed takes into account the interaction of production and maintenance aspects. For this purpose, a discrete-event production-oriented simulator (MELISSA-C++) has been extended to incorporate equipment failures and maintenance operations, thus modeling residual breakdowns, occurring in a combined corrective/PM context. The usefulness of the simulation tool has also been demonstrated for the estimation of both direct and indirect maintenance costs, which are impossible to determine empirically due to the reentrant nature of product flows in a semiconductor manufacturing facility. The results obtained have confirmed the marked effect of equipment characteristics (bottleneck or non-limiting step) on maintenance cost evaluation. Following a tutorial example, typical results are presented and analyzed.

Keywords: Maintenance; Scheduling; Semiconductor manufacturing; Optimization; Reliability; Replacement

1. Introduction

A special configuration of a batch facility, which is by far the most complex one, is the multipurpose plant. This kind of workshop is characterized by a great number of batch manufacturing processes and equipment, by a reentrant flow of products and by numerous non-predictable situations such as operator unavailability, storage limitations, flow bottlenecks and, especially, equipment failures. In this context, maintenance and reliability play a major role in process operations.

The work presented in this paper examines the interaction effects of maintenance policies on batch plant scheduling in a semiconductor wafer fabrication facility. A simulation model previously developed in our laboratory (Navarre, Pantel, Bérard, Pantel, & Pibouleau, 1998; Peyrol, Pibouleau, Floquet, Couderc, & Domenech, 1993), designed for ideal equipment behavior, has been extended to incorporate equipment failures, set-up and repair times as well as maintenance operations. The model has been validated in an industrial context (MOTOROLA semiconductors in Toulouse, France).

The purpose of this work is the improvement of the quality of maintenance department activities by the implementation of optimized preventive maintenance (PM) strategies and comes with the scope of the so-called total productive maintenance (TPM) strategy (Pimor, 1991).

This paper is composed of five sections. First, a brief description of semiconductor processes and related maintenance activities is proposed; second, the area of maintenance modeling and optimization is analyzed and the methodology for maintenance optimization in a wafer fab is presented. The third part deals with the problem of modeling both production and maintenance activities in a semiconductor environment; mathematical representation of breakdown phenomena and maintenance and its integration in a discrete event simulator (DES) are discussed. In this section, the interdependency

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Nomenclature

$C_{SP\text{-}CO}$	spare parts cost (FF)
$C_{SP\text{-}PM}$	spare parts cost (FF)
D_{CO}	corrective intervention duration (h)
D_{PM}	corrective intervention duration (h)
H_{CO}	hourly manpower cost(FF/h)
H_{PM}	hourly manpower cost (FF/h)
T_{NP}	non-production time (min)
H_{PW}	number of lots produced per hour (wafers/h)
N_l	number of lots having waited in front of equipment following its breakdown (wafers)

between preventive and corrective actions is widely presented. Typical results obtained by the simulation tool are analyzed. The next section is devoted to the methodology for determination of optimal PM frequency for equipment. General considerations about maintenance costs are also presented. Finally, conclusions and perspectives are suggested.

2. Brief description of semiconductor manufacturing processes and related maintenance activities

2.1. Typical manufacturing processes

Semiconductor devices are built upon thin wafers of silicon. These wafers are typically between 4 and 10 inches in diameter. The devices vary in complexity from a few thousand to a few million transistors. The production of semiconductor devices is carried out in a so-called clean room, commonly referred to as a wafer fab, typically divided into different zones requiring different levels of cleanness. Wafers move through the fab in lots, often of a constant size based on standard containers. The production of semiconductors is achieved in a multistep process involving a variety of complex chemical processes which can be divided into unit operations, i.e. deposition, photolithography, etching, ion implantation, photoresist strip (see Uzsoy, Lee, & Martin-Vega, 1992, 1994 for an overview of the semiconductor manufacturing processes).

A typical semiconductor factory contains hundreds of processing machines, personnel and various tools such as lithography masks for projecting patterns onto wafers. The machines exhibit a wide variety of characteristics. Each equipment unit is associated with one of the unit operations involved in the global process. It is quite common that an individual lot visits one or more equipment units repeatedly during its course. In particular, each lot visits many times the same lithography or ion implantation workstation repeatedly, giving the resulting process a cyclic character (Fig. 1). On the contrary, deposition equipment and plasma etchers are often dedicated to a single operation to prevent contamination.

Since a semiconductor facility is a multipurpose plant, the various product families have different flows through the workshop. The processing times are predetermined and different products may have different processing times on the same equipment unit. Another detail is that equipment units with different processing capabilities may be found. So, on the one hand, the lots belonging to the same family of products arriving at an equipment unit superior in capacity to one lot are processed simultaneously (the number of lots to be regrouped is equal to the capacity of the workstation). On the other hand, lots arriving at a process step inferior in capacity to one lot are split into smaller lots. After its traveling through this step, this lot is merged if necessary with another lot of its family. Also note that the wafers are not generally subject to any risk of contamination or yield loss and can thus be stored with no problem. Loading/unloading, cleaning, measurement, inspection operations are performed throughout the fab by multi-skilled operators.

2.2. Maintenance activities in a wafer fab

In this production environment, equipment breakdown or procedure drifting usually induces unscheduled production interruptions. Preventive interventions are also carried out in order to minimize the probability of unscheduled production interruptions. All these elements combine to render the task of managing material flow through these facilities challenging.

Generally, the maintenance department performs:

- Corrective maintenance (CO), as a consequence of a breakdown.
- PM to avoid a possible breakdown (thus reducing breakdown probability). This work is focused on systematic PM, which performs preventive interventions on the basis of scheduled maintenance actions. Of course, this policy presumes a good preliminary knowledge of the material or equipment behavior, which is typically the case in semiconductor manufacturing.