行政院國家科學委員會專題研究計畫成果報告

晶圓廠整體設備效能提昇與管理系統(1/2)－總計畫

Enhancement and Management Systems for
Overall Equipment Effectiveness of Wafer Fabs

計畫編號： NSC 88-2212-E-002-061
執行期限： 87 年 8 月 1 日至 88 年 7 月 31 日
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一、中英文摘要

晶圓廠整體設備效能損耗的原因主要是設備速率或負載損失、設定轉換、機台閒置、品質損失、設備維修、測試晶片佔用等。針對這些損耗的原因，本計畫探討設備監看、預防保養、工作區排程、設備組態設計、設備指派運用、整體效能分析與提昇策略等方面的效能提昇方法。本計畫之第一年成果包含物件導向工廠模擬器、機台組態方法與軟體、叢聚式機台的效能分析模型及工作排序工具、設備之健康指數與預防保養模式。

關鍵詞：設備整體效能、晶圓廠模擬、晶圓廠排程、組態設計、預防保養

Abstract

The major categories for equipment effectiveness loss are speed loss, equipment setup, equipment idleness, unsatisfactory product quality, unscheduled downtime, and test wafers. The goal of this project is to develop methodologies, tools, and a management system for enhancing overall equipment effectiveness of wafer fabs. Methods for enhancing equipment effectiveness in the areas of equipment monitoring, dynamic preventive maintenance, job dispatching, tool scheduling, machine assignment, tool portfolio design, and OEE analysis and management are investigated in this project. The preliminary results for the first year include a factory simulator, tool portfolio planning methods and software, analysis and sequencing methods for cluster tools, and equipment health indices and prognosis models.

Keywords: Overall equipment effectiveness, factory simulation, intra-bay scheduling, tool portfolio planning, equipment health index, preventive maintenance

二、計畫緣由與目的

半導體產業目前正遇到「資本效率」方面的一個新挑戰，晶圓廠一般設備的平均有效使用率只有 35%，當晶圓廠資本需求持續地增加，許多廠商將沒有能力負擔新世代晶圓廠的重置成本，因此「資本效率」的提昇不僅攸關半導體產業未來成長的趨勢，對個別廠商而言，提昇設備生產力更可以顯著降低製造成本，創造獨享的競爭優勢。

設備整體效能的損耗原因很多，涵蓋機台、製程、生產管理、工廠組態設計等領域。晶圓廠內由產品、製程、機台及運作方法不斷更新所帶來的多樣性往往導致許多變異性，增加了效能損耗的複雜度。本計畫針對提昇策略與資訊分析、工廠系統、作業區、個別設備等四個大方向，由宏觀至微觀，分四個子計畫進行（團隊成員有楊烽正、周雍強、張時中、陳正剛、郭瑞祥）：

(1) 設備整體效能分析與模擬系統
(2) 晶圓廠組態設計與設備運用
(3) 工作單元設備效能導向之作業排程
(4) 半導體設備監看與預防保養

三、研究方法

針對設備整體效能損耗的各項類別，各子計畫的研究範圍列舉在表（一）。子計畫（一）的目標是建立設備效能分析與提昇策略規劃的資訊系統平台。在本計畫執行中將作為各子計畫效能資料與分析模式的整合中心，計畫完成之後可成為實用的設備整體效能管理系統。子

計畫（二）與（三）是以系統層次的設備整體運用為改進目標。子計畫（二）之重點在整廠製造資源組態與非即時性(non real-time)的機台指派決策；子計畫（三）則以工作區(work area)即時性的生產排程與派工決策為重點。針對晶圓廠機臺工作順序及工作單元內晶圓派工的排程問題，進行以裴氏網路的理論及技術設計叢聚式機臺設備的效能分析模型及工作排序工具。子計畫(四)之目標在發展設備監看的方法以及根據設備狀態而定的動態預防保養決策。這四個子計畫廣泛涵蓋由工廠系統到個別設備、由中期決策到即時決策的「設備整體效能」提昇方法。

表一：各子計畫的範圍

整體效能損耗的類別	各子計畫範圍			
	一	二	三	四
速率損失	√	√	√	
設定轉換	√	√	√	√
閒置–需求與排程	√	√	√	
閒置– no operator	√	√		
閒置– no product	√	√	√	
品質	√			√
意外當機	√			√
測片	√		√	√

四、結論與成果（計畫結果自評）

本計畫之第一年成果包含物件導向工廠模擬器、機台組態方法與軟體、叢聚式機台的效能分析模型及工作排序工具, 及設備之健康狀態指數與預防保養模式。本計畫之部份成果也已移轉給聯瑞積體電路公司。

IEEE、SEMI 等協會主辦的 International Symposium on Semiconductor Manufacturing 是半導體製造領域最主要的國際研討會, 每年十月輪流在美國與日本舉行。今(1999)年共有 223 篇論文投稿, 每篇論文都經過四十餘位國際專家嚴謹審查，只有 30%論文獲得口頭報告的殊榮，20%論文為 posters。本年入選的 113 篇論文中，有 11 篇出自台灣半導體產學界。本計畫研究團隊總共獲選 7 篇（表二），並且在 69 篇口頭報告中獨佔 6 篇, 為我國在半導體製造的國際學術領域取得顯著地位。

表二：本計畫在 ISSM ’99 發表之論文

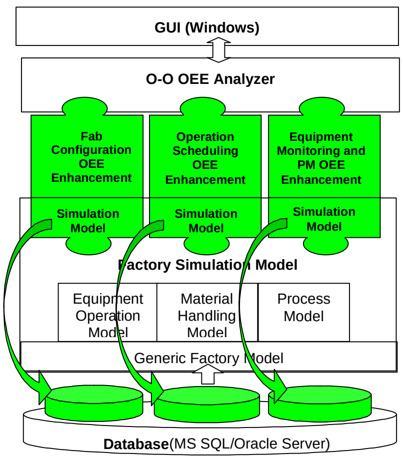
Area	Paper Title	Author
Manufacturing Strategy and Structure	Product mix planning	周雍強
	Function-based cost modeling	郭瑞祥 陳正剛
	Tool portfolio planning	周雍強
Manufacturing Control and Execution	Fab scheduling rule selection	張時中
Process and Material Optimization	Run to run control of CMP process	陳正剛 郭瑞祥
	Spatial uniformity of rapid thermal oxidation	郭瑞祥 陳正剛
	End-of-line SPC monitoring	張時中 郭瑞祥

五、子計畫研究說明

子計畫(一)：設備整體效能分析與模擬系統

針對模擬晶圓廠製造活動，本研究提出訊息傳遞式物件導向模擬方法, 根據整體設備效能分析模擬的需求，分析並設計了必要的系統架構、並實作一個晶圓廠雛形模擬模型。

圖(一)為模擬系統架構圖，模擬框架的核心部份是一個物件導向模擬模型(factory simulation model)，包含設備作業模型、物料搬運模型及生產作業模型等三個部分, 並定義了整合介面的基本需求。

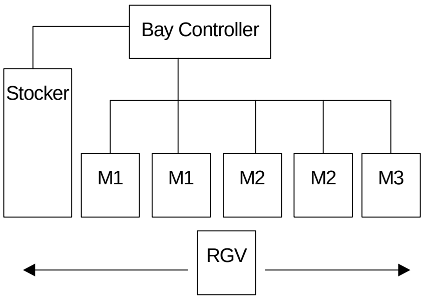


圖一： OEE分析模擬系統架構

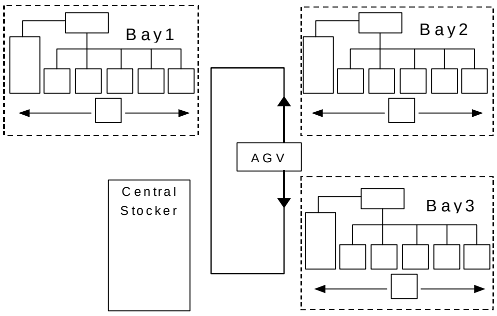
設備作業模型中定義了機群與機台的狀態變化。本年完成的雛形模式中包含閒置、忙碌與等待物料等 SEMI E10 中的三種狀態，其他狀態將在未來添加。生產作業模型中定義了晶圓製程

的表示方法及各個加工批量之加工進度的追蹤方式。產品的製程現階段只規劃到機群，並以動態派工（先進先出）方式指定機台。物料搬運模型中定義了搬運命令的格式。一個搬運指令只包含搬運起點、搬運終點與欲搬運物料三項資訊。

本計畫使用 MS Visual C++語言實作了一個晶圓廠雛形模擬模型。圖（二）顯示一個工作區，包含機台（三個機群）、搬運車及自動倉儲。整廠雛形模式由工作區組成（圖三）。工作區間的派工及工作區間搬運命令的工作由一個整廠控制器負責。



圖二： 工作區配置



圖三： 雛形模型整廠架構

子計畫（二）：晶圓廠組態設計與設備運用

本計畫工作項目有：

- µ 分析產能與機台組態之規劃程序
- µ 發展產能計算模式
- µ 發展機台組態的規劃方法
- µ 發展機台備援規劃的方法
- µ 構建出決策資訊系統

本計畫獲得聯瑞積體電路公司提供的製程、機台設備資料，進行十餘次的小組訪談與討論，發展數學運算模式，開發軟體決策系統的雛形，並以移交該公司使用。

本計畫除了發展規劃設計方法之外，還利用 Microsoft Visual Basic 與言語 Access 資料庫系統實作軟體決策系統，主要成果有：

- µ 晶圓廠靜態產能模式
- µ 晶圓廠等候限產能模式
- µ 機台組態設計方法
- µ 機台組態設計的軟體決策系統

子計畫（三）：工作單元之作業排程

A sequencing and performance analysis tool has been developed for PVD cluster tools. The tool has four function modules: a Petri-net (PN) modeler, a simulator, a performance analyzer and a sequencer [8].

1. Petri net-based modeler

The modeler is based on physical configuration, operations and process flow information of cluster tools and captures problem features in resource sharing, concurrency, process sequences and flexible routing. The modeler takes a modular composition approach. For the PVD example, PN sub-models for cassette, transport, and process modules are first constructed respectively. Submodels are then automatically synthesized into a complete PN model by the modeler.

2. Performance analyzer

Two performance metrics of a PN model are analyzed in this module: (1) cycle time per wafer and (2) tool bottleneck identification. Ramamoorthy and Ho's PN cycle search and time calculation algorithm [9] serves as the core technique. Given a PN model of a cluster tool's processing times, cycle times can be quickly calculated and bottleneck identified by the analyzer.

3. Sequencer

With the PN model of cluster tools, an operation sequencing problem can be easily formulated as a discrete, integer programming problem. In our current implementation, tardiness is chosen as the objective function. Two heuristic algorithms are proposed to solve this sequencing problem of the PVD tool named m-A* search and FS search algorithm. Numerical cases have been used to demonstrate the feasibility and optimality of our sequencing algorithms. In our test cases, both m-A* search and FS algorithm achieve a better performance than using FIFO sequencing. The m-A* search and FS algorithm outperform FIFO by about 20% and 17% respectively in the metric tardiness.

4. Simulator

The simulator adopts a Petri net model-based simulation package Design/CPN. It takes a PN model built by the modeler and evaluates the detailed tool performance under specific operation sequences. It may serve as a wafer movement predictor for the next few hours and supplements the function of performance analyzer.

子計畫(四)：半導體設備監看與預防保養

Scheduling of preventive maintenance used to be scheduled based on MTTF (Mean Time To Failure) statistics. Modern equipment provides many real-time state data such as temperature, current, vibration, corrosion, fluid, etc. These data are cross-correlated. In this study multivariate process capability indices (PCI's) are utilized to predict the health of equipment based on real time equipment state.

Multivariate PCI's have been used for measuring process performance by product's quality characteristics. But the basic theory is also feasible for evaluating equipment capability.

Let $X_1, X_2, \ldots, X_k$ be k important parameters for machine state, and all follow normal distributions. A *Machine Capability Index* (MCI) can be defined as follows

$$MCI = \frac{area \quad of \quad (\mathbf{X}-\hat{\mathbf{i}})^{'}\mathbf{A}^{-1}(\mathbf{X}-\hat{\mathbf{i}}) \le K^2}{area \quad of \quad (\mathbf{X}-\hat{\mathbf{i}})^{'}\mathbf{V_0}^{-1}(\mathbf{X}-\hat{\mathbf{i}}) \le í^{2}_{з,0.9973}}$$

where

$\overline{\mathbf{X}}$ is the sample mean vector of $\mathbf{X}$

$\mathbf{V_0}$ is the var-cov matrix of $\mathbf{X}$

A is a variance-covariance matrix

The denominator can be regarded as '*performance region*' and the numerator as '*specification region*'. $\boldsymbol{\xi}$ is the mean vector. The 'size' of specification region is controlled by tuning K.

The MCI with a range of $(0,\infty)$ is transformed to a score with the range of [0,100] to grade machine performance.

$$H = (1-e^{-\frac{MCI}{d}})(1+e^{-\frac{MCI-a}{d}})^{-1} \times 100$$

Equipment health index is regarded as a *Markovian* stochastic process, $H=(H_t : t \ge 0)$ by discretizing the continuous health index into a finite number of segments. Let $S=\{S_1, S_2, \mathrm{K}, S_{n-1}, F\}$ be the state space and Φ denote the matrix of one-step transition probabilities $P_{i,j}$. When a machine is down, the failure state F (an absorbing state) is reached:

$$S_n=F,\ P_{F,F}=1,\ P_{F,j}=0, \quad for \quad j=1,2,\mathrm{K},n-1$$

One of the most important properties of above proposed prognosis model is the bell-shape probability distribution presented by entries in the same row of Φ. But as the machine grows older the health index H tends to worsen due to the deterioration of equipment. Let a larger value of state correspond to a better health index score. Each row of matrix Φ will look like a moving wave when the equipment ages. The transition probability is modified for the prognosis model:

Let $P_{i,M}$ be $\max_j\{P_{i,j}, j=1,2,\ldots,n\}$ and Q be any state to the left of state M.

Denote $P_i^L = \sum_{j=1}^{Q-1} P_{i,j}$ and $P_i^R = \sum_{j=Q}^{n} P_{i,j}$. As a machine ages, $P_i^L(t) \le P_i^L(t+1)$ and $P_i^R(t) \ge P_i^R(t+1)$.

Let $\text{¢} = \dfrac{P_i^R(t+1) - P_i^R(t)}{P_i^R(t)}$ be the aging factor, $\text{¢} \in (0,1)$.

Suppose the amount of increase or decrease in $P_{i,j}$ is proportional to the fraction $P_{i,j}$ in $P_{i,L}$ or $P_{i,R}$.

$$P_{i,j}(t+\Delta) = P_{i,j}(t)\cdot(1+\frac{P_i^R(t)}{P_i^L(t)}\text{¢}) \quad \text{for } j<Q$$

$$P_{i,j}(t+\Delta) = P_{i,j}(t)\cdot(1-\text{¢}) \quad \text{for } j \ge Q$$

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