Development of Remote Control System of a Semiconductor Cluster Tool

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Abstract

In recent years, the manufacturing industry of semiconductor is prosperous in the world, and the cluster tool is developed for the purpose of wafer processing. In this paper, the architecture and development for remote diagnosis and preventive maintenance of a cluster tool will be proposed. Firstly, the cluster tool simulator is constructed by using Petri net, and a selection engine of dispatching rules is added to the simulator. Besides, a statistical process control (SPC) module and a preventive maintenance (PM) module are connected to the simulator for a better monitoring.

Finally, a three-tiered architecture of remote control system is constructed for cluster tools. For the sake of concurrency and data extraction, only some important events, rather than all data are transferred to remote browsers. By the detection of the cluster tool and the diagnosis in the local controller, maintenance engineer can monitor the efficiency and failure of the cluster tool by remote browser. A better method is chosen from the diagnosis results and is used as the basis of on-line recovery, or the reference to inform related staffs.

Keyword: remote control, cluster tool, Petri net, SPC, preventive maintenance

1.Introduction

The cluster tool consists of transfer module, process module, and cassette module. Each module can be modeled independently. Various Petri nets [6] have been applied to flexible manufacturing systems (FMS) [2,[13], and the Distributed Colored Timed Petri Net (DCTPN) can be applied to a distributed manufacturing system, such as an FMS.

The scheduling and dispatching are important subjects for a manufacturing system. Many dispatching rules were proposed to enhance performances. The selection of an optimal dispatching rule is usually proceeded off-line. The paper about on-line rescheduling of dispatching rules will keep the current states to follow the objective of good performance, and Tsai [11] proposed four generic dispatching rules to improve the performances such as cycle time, throughput rate, and machine mean utilization.

A cluster tool is a kind of flexible manufacturing systems (FMS), and the control strategy such as statistical process control (SPC) module and preventive maintenance (PM) module will help the cluster tool works smoothly. The SPC and Run-by-Run method will improve the reliability and precision of products. The PM module can reduce the unexpected breakdown situation. Lee [3] [4] and Shi [10] proposed the method of remote diagnosis and monitoring for machines. For the purpose of improving the correction of diagnosis, Lee [5] constructed a remote diagnosis platform by using expert system.

In addition, because the Internet is used frequently, receiving data from the web browser is popular. Brady and Tarn [1] proposed an event-based control through Internet. The motion of remote robot is cut into several events and the controller will respond to these events. A well-designed web server can deliver the tool messages to a generic browser, and the operators can use the web browser to monitor and control the equipment.

2. Dispatching Rule Selection Engine for Cluster Tool Models

2.1 The Environment of Cluster Tools

A cluster tool is an integrated and environment isolated wafer-manufacturing system. It consists of three main parts: processing chambers, transferring module, and cassette module. A wafer is initially placed in a cassette and when the wafer is ready to be manufactured, the cassette is placed in the cassette module, the loadlock. The wafers are transferring between two chambers using a robot arm inside the transferring module. Each processing chamber can process wafers for different requirement, such as the implantation, coating, CVD, PVD, HTCVD, and RTP CVD, etc. Due to the characteristics of isolation, the breakdown of one chamber will not essentially cause other chambers to breakdown.

2.2 Dispatching Rule Selection Engine

Because not all the dispatching rules are fitting for all conditions of a cluster tool, Tsai [11] proposed four generic dispatching rules to deal with all conditions, as shown in Fig. 1. With the combination of the four generic dispatching rules, the cluster tool will decide a wafer ready for manufacturing in the buffers. From the research of Tsai [11], every performance criterion has three sub-optimal dispatching rules for the wafer based and robot-wafer based dispatching rules. The best three dispatching

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rules are shown in Table 1, and these dispatching rules are called sub-optimal dispatching rules.

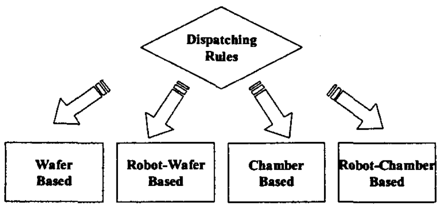


Fig. 1 Four generic dispatching rules

Table 1 Sub-optimal dispatching rules for some performance criteria

Performance Criteria	Sub-optimal Dispatching Rules		
Cycle Time	LMT	LPMRW	LPT
Throughput Rate	LPMRW	LMT	LPT
Mean Machine Utilization	LMT	LPMRW	LPT

When the sub-optimal dispatching rules are applied to a cluster tool, the performances of the wafer recipes in the loadlock can be calculated by using three sub-optimal dispatching rules. After the performances have been compared, the dispatching rule is chosen with the best performance.

The engine will load the data from the wafers preparing for manufacturing in the buffer, and calculate an optimal dispatching rule for these data. The engine will notify the DCTPN to change to the selected dispatching rule. The on-line re-dispatching procedure is shown in Fig. 2. The time spent in calculating the data is about 15 seconds in the real world, and the states after calculation are assumed to change little compared to the states before calculation.

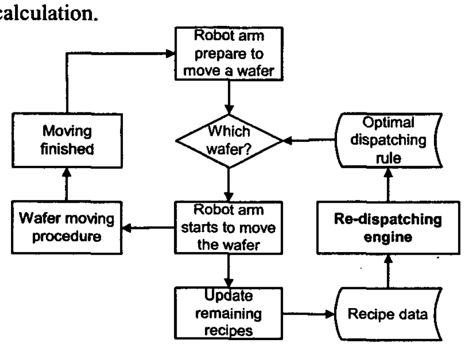


Fig. 2 The on-line re-dispatching procedure

2.3 Simulation Results

When the DCTPN represents the cluster tools, the modules will be modeled as a sub-net. Every sub-net will communicate to each other by the protocol of NTU-Net. Because of the usage of COM technology, the procedure of calling COM should work precisely. The cluster tool modeled in this paper is a hexagon. Two sides are occupied by the loadlocks, so only four sides can be connected to four process modules. There are five processes will be modeled. The processes are RTO, RTP CVD/polysilicon, RTP CVD/nitride, cleaning, and ellipsometer. Besides, the first and the sixth chambers are connected to loadlock 1 and loadlock 2, respectively.

Five dispatching rules are applied to the cluster tool model, and the performance of cycle time is the main performance index. The dispatching rules are (1) FCFS, (2) LMT, (3) LPMRW, (4) LPT, and (5) selection engine results. For the simulation with ten kinds of recipes, the cycle time is shown in Table 2. The value of clock means the clock ticks spent from the first cassette started to the last one finished. The physical meaning of 1000 clock ticks is one day in the real world. Another value for each dispatching rule is the clock ratio of every dispatching rule to selection engine.

Table 2 Simulation results

Cycle Time / Dispatching Rule / Simulation	FCFS		LMT		LPMRW		LPT		Selection Engine
	Clock	Ratio	Clock	Ratio	Clock	Ratio	Clock	Ratio	
1	6467	1.25	6527	1.27	6219	1.21	6162	1.19	5158
2	5620	1.26	4542	1.02	5547	1.24	5137	1.15	4472
3	3231	1.30	2494	1.00	2717	1.09	3058	1.23	2494
4	7217	1.16	6842	1.10	6325	1.01	6650	1.07	6240
5	4251	1.25	3955	1.17	3542	1.04	4128	1.22	3394
6	11984	1.16	10867	1.06	10939	1.06	11587	1.13	10294
7	1989	1.30	1725	1.13	1863	1.22	2154	1.41	1525
8	3122	1.05	3049	1.02	3262	1.09	3289	1.10	2981
9	4963	1.26	4622	1.17	4098	1.04	4816	1.22	3944
10	2069	1.27	2392	1.47	2096	1.29	2017	1.24	1631

The results show that the on-line selection engine will obtain a shortest cycle time than FCFS, LMT, LPMRW, and LPT. The results ensure the correction of selection engine in general recipes.

3. Local Controllers of Cluster Tools

A local controller of a cluster tool can receive messages from sensors in the cluster tool, and control the cluster tool hardware. The cluster tool controller is composed of several modules, as shown in Fig. 3.

The DCTPN models will simulate the cluster tools, and the simulation results can provide reference for cluster tool action. SPC and Run-by-Run module will receive the measured value from sensors of the cluster tool and highlight the warning value. A PM module can estimate the mean time between failures and help operators schedule the PM procedure.

An intelligent module can handle the low level action of the cluster tool, and the virtual machine module acts as a cluster tool simulator. The alarm and error module will handle alarm and error messages from the cluster tool or virtual machine module. A command module can send a command to the cluster tool to stop or start machines.

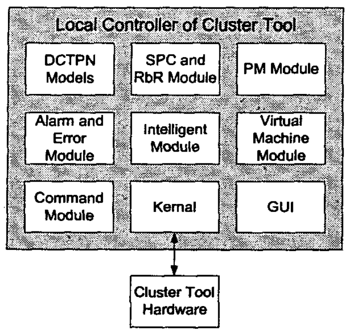


Fig. 3 The local controller of cluster tool

3.1 Cluster Tool Status Viewer

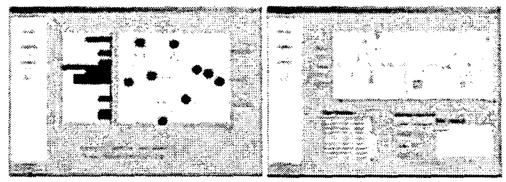
When a cassette is sent to the loadlock, the recipe and the amount of wafers in the cassette will be sent to the cluster tool status viewer. The viewer will monitor the on line status of cluster tool.

3.2 Statistical Process Control (SPC) and Run-by-Run (RbR) Module

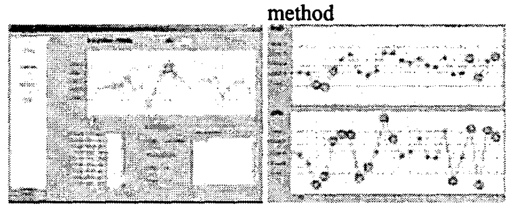
The SPC and RbR module is a local controller dealing with the quality of products of a cluster tool, and the module is constructed using COM+ event-driven template. Both of the SPC and RbR module are represented in Fig. 4.

- Trend chart: The trend chart will show the ratio of the measured data to the desired data. When the UCL, CL, and LCL are decided, the capability of precision (C_p), the capability of accuracy (C_a), and process capability (C_{pk}) can be calculated immediately.
- Histogram: The histogram applied here will show the distribution of the trend chart.
- Control chart with Nelson violation rules: The Nelson violation rules will be applied to the control chart. When the data violate the rules, the points in the control chart will turn to a red circle with a cross mark in it. Every Nelson violation rule reflects a kind of problems and strategy.
- Control chart with RbR method: The EWMA method is selected as our RbR method. When the EWMA method is applied to the control chart, the value of the next point is predictable. The Nelson violation rules are also added. The value of w in the EWMA equation will be tuned manually.

The results will provide the indices for diagnosing the quality of products, the degradation of the equipment, and the stability of operation environment. The comparison of SPC and RbR method is shown in Fig. 4 It is obvious that SPC method reflects the variation directly. On the contrary, the RbR method feedbacks the alternation and reduces variation. The warning points of RbR method are less than those of SPC method.



Trend Chart and Histogram Control chart with RbR method



Control chart with Nelson violation rules Comparison of SPC and RbR method

Fig. 4 SPC and RbR module

3.3 Preventive Maintenance (PM) Module

The other factors affecting the cluster tool are the worn rate and the PM period. The worn rate is regarded as the use rate, and the PM period depends on the use rate. When the time is close to the predicted PM point, an alarm will be generated. The definition of one cycle of the cluster tool is that the robot arm completes a transferring procedure. The use rate is then defined as the total cycles of a cluster tool in a day (cycles / day). There are three ways to determine the use rate.

For immediate prediction, the latest data of the use rate are applied. Usually, the latest data comes from the last working day, and the use rate can reflect the immediate situation. If the use rate changes violently, the average of use rates will reflect a long-termed prediction. The moving average of the use rates of the last seven days (one week) is applied for a steady prediction. The third way uses the EWMA method to predict the use rate. The prediction of the use rate results from the last prediction and last real data of use rate. When the use rate is decided, the days remained to proceed PM are also calculated. The remained days to proceed PM will be sent to the central controller.

4.4 Diagnosis Server for the Cluster Tool

There are three types of alarm data in the cluster tools, including SPC results, error symptoms, and machine status. Two of them need to be diagnosed. The SPC and RbR results are the first alarm type from product quality and machine environment. When the alarm messages involve in the process capability (C_p, C_a, C_{pk}) and violation rules, the degrees of process capability and violation rules will reflect the status of machines, products, and environment.

A breakdown situation will not always accompany with an error code. When the cluster tool does not generate error codes, the breakdown situation will be judged by the IICBR method. Operators will acquire the component status by local observation or remote monitoring, and collect the symptoms. The symptoms as key words will be imported to diagnosis server interface. The diagnosis server will search the failure cases and pick up the similar cases sorted by similarity. When one of the possible cases is selected, the recommended action will be displayed. The diagnosis server will be integrated with a web server. The user can diagnose the alarms through Internet.

4. Implementation of Remote Control for Cluster Tools

4.1 The Architecture of Remote Control System for Cluster Tools

The architecture of the remote control system of the cluster tool is three-tiered. Fig. 5 shows the relation of each tier. The first tier is a local controller. The controller manages the data collected from the cluster tools, and preprocesses the data. The second tier receives preprocessed data from the first tier, and judges the failure type of the cluster tool. After determining the failure of the cluster tool, the controller will diagnose the data, and show all the methods used in the failure analysis. Engineers can choose one of these methods to proceed to maintenance procedure. At the third tier, operators can use generic browsers, such as IE or Netscape, to see what happens to the cluster tool.

4.2 Constructing Three-tiered Architecture of the Remote Control System

After introducing the architecture of the remote control system of the cluster tool, the functions of all tiers will be set.

■ The First Tier

The research emphasis here is how to determine the failure state in the data collection and pre-processing stages. Only meaningful data and messages will be processed and sent to the second tier.

■ The Second Tier

Several servers constitute the second tier. If the message type from the first tier is an error or failure, the message will be sent to the alarm server. The server will send the messages to the third tier. The other server existing in the second tier is the diagnosis server. The diagnosis server deals with the message of errors and failure, and the construction of the diagnosis server is focused on the engineering knowledge and diagnosis requirements.

■ The Third Tier

The remote browser is the third tier. Because the technology of Active Server Page (ASP) is used, the users from the third tier can use any generic browser, such as IE or Netscape, to connect the server in the second tier.

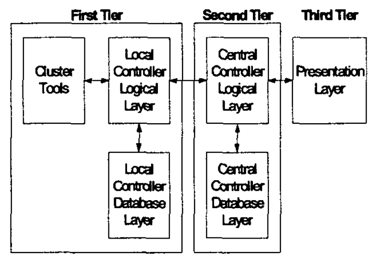


Fig. 5 The architecture of remote control system on cluster tools

4.3 Message Flows in the Remote Control System

■ The First Tier

The message flows in the first tier are shown in Fig. 6. There are four main kinds of raw messages flowing from a cluster tool to the first tier, and after preprocessing; they will become a valuable data.

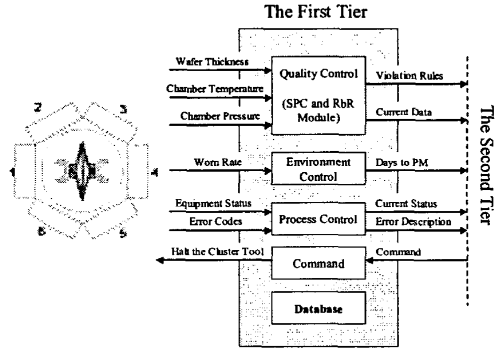


Fig. 6 The message flows in the first tier

There are four main kinds of messages sent to the second tier. They are (1) the quality of the products, (2) the condition of cluster tool, (3) process control, and (4) the vision monitoring of the local machine.

There are two major control responses of the cluster tool in the first tier. The first is the command sent from the second tier. The first tier is like a virtual machine, and transforms the command from the second tier to SECS-II format. When the transformation is complete, the message in SECS-II format will be sent to the cluster tool. The second response is the determination of the wafer recipe.

■ The Second Tier

The first tier of the remote control system is the local controller of the cluster tool, and the second tier is the central controller of the cluster tool. The central controller will receive the data from several local controllers; even local controllers are located in a foundry Fab. The message flows in the second tier are shown in Fig. 7. There are three servers to deal with the data flows, and five main preprocessed data sent from the first tier to the second tier.

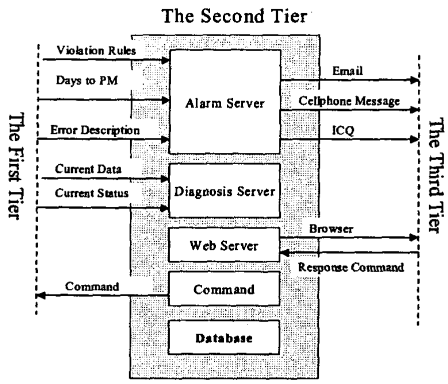


Fig. 7 The message flows in the second tier

The alarm server is a server to deal with the alarm procedure. The web server of the second tier conducts the data exchange of the web browsers. The diagnosis server will receive the symptom, which is equal to the alarm, and choose a most possible solution.

■ The Third Tier

Operators can receive the alarm message or other information from the second tier through the web browser, email, or cellular phone. When the operator has received the message, he will reply to confirm receiving. If the operator does not reply the message, the message will be sent again in a period of time. In addition to the confirmation reply, the operator can send commands to the second tier to control the cluster tool. The message flows in the third tier is shown in Fig. 8.

5.2 Alarm Messages

There are five web pages to display alarm messages.

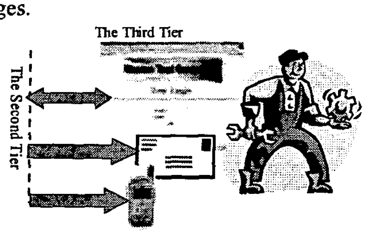


Fig. 8 Message flows in the third tier

- The product capability web page: it will display out-bound product capability of wafers. Operators can monitor the alarm message and confirm the message by clicking the button in Machine ID column shown in Fig. 9. If the operator does not confirm the alarm message, the message will be sent again by email and cellular phone after alarm timeout.
- The violation rule web page: it will display the violation rules caused by wafer measurement, temperature, and pressure value of a RTP CVD chamber. The operator can also monitor the data and confirm on-line.
- The Run-by-Run (RbR) web page: it will display the violation rules caused by wafer measurement in RbR method.
- The PM web page: the operator can monitor the PM web page and understand which component is preparing for PM procedure.
- The error code web page: it will contain the error codes generated by the cluster tool. The error code will contain symptoms and recommended actions.

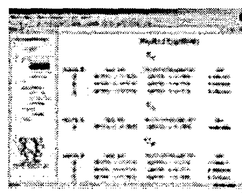


Fig. 9 Alarm messages of wafer quality

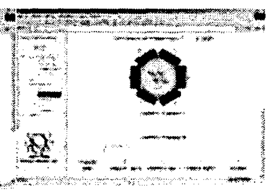


Fig. 10 The chamber status of a cluster tool

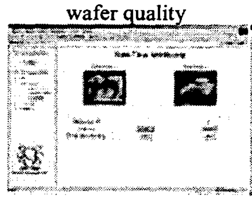


Fig. 11 The real-time monitoring of the cluster tool

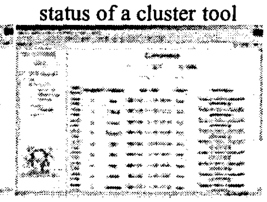


Fig. 12 The confirmation of command and historical command record

5.3 Cluster Tool Status

The chamber status web page can display the availability of all chambers. The chamber status web page is shown in Fig. 10.

5.4 Image Monitoring

The image monitoring web page will display the images, and the images are shot by the local camera. The operator can see the images to collect the failure symptoms, and transfer the symptoms to the diagnosis server to judge the failure situation remotely.

5.5 Submitted Commands

The operator can send two kinds of messages to the local controller with remote browsers. The first is the confirmation reply. The second is command submission. The submitted command will be sent to the local controller. One or more operators will submit commands to a cluster tool remotely and locally, and the local controller will conduct the conflict situation. The submitted command will be displayed in the historical command records. The command web page is shown in Fig. 12.

6. Conclusions

Cluster tools can be modeled as DCTPN graph. An optimal dispatching rule will be calculated with the current data in the DCTPN graph, and the characteristics of proactive trigger and on-line calculation will provide the engine to keep the selected dispatching rule to be optimal when the data varies with time. The engine will select a best performance using of the three sub-optimal dispatching rules (LMT, LPT, and LPMRW) to maintain a small cycle time.

By the construction of COM+ event-driven template, the local monitoring of the cluster tool model will be achieved. One viewer and two modules are added to monitor the cluster tool model. A SPC and Run-by-Run (RbR) module will receive the measured data and turn into process capability, violation rules, and predicted data. A PM module will predict the mean time between failure (MTBF), and send an alarm if the MTBF is less than a warning period. By a diagnosis mechanism, the alarm message will extract a best solution from solution sets by more symptoms.

The remote control system of a semiconductor cluster tool includes a three-tiered architecture. The first tier will extract the alarms and errors from the raw data sent from the cluster tool. The second tier is a central host, and collects the alarms and errors. When the alarms and errors have been received, an alarm server and a web server will send them from the second tier to the third tier. The third tier represents the remote users, and by the use of Internet, users will receive the alarm and error messages from the web browser, email and cellular phone messages. A user might send a command of to stop a machine or diagnose the messages.

Acknowledgement

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