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Data acquisition system of compound semiconductor fabrication

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Abstract

Though compound semiconductor manufacturing technologies are very much similar to those of the silicon series memory devices, the production process control technologies tend to rely on the experiences of operators and managers because the production technology suitable for the characteristics of compound semiconductor fabrication has not yet been sufficiently developed, compared with that of silicon semiconductors. In addition, the semiconductor industry is being converted into mass customization production and an open foundry service for cooperation between businesses. In this study, a process data acquisition system suitable for compound semiconductors which collects data by operator input and equipment information extraction by using GEM was developed. The developed system was implemented in a real production system and compared with the conventional job card method. Through the application of the developed system, a foundation for constructing a real-time based MES (Manufacturing Execution System) was developed, with such expected effects as process information monitoring, meeting delivery schedule, and reducing lead-time.

Keywords: Data acquisition system; Foundry service; Mass customization; MES; Compound semiconductor

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1. Introduction

Semiconductor fabrication technologies consist of a device technology which develops the structures of semiconductor devices, a design technology which evaluates the performance and process of the devices, a process technology for production, and a production management technology which integrates the aforementioned technologies and controls on-site equipment and process information.

Compound semiconductors which make use of the group-3 to group-5 elements, whose semi-conductive characteristics were identified in the early 1950s, have been developed and mass produced since the early 1980s by several companies. Compound semiconductors have been used in infrared LEDs for sensors, blue LEDs for sign boards, and white LEDs - which are expected to substitute the lighting device market. Recently, according to the development of information communication technologies, they have been incorporated into information communication devices such as the MMIC (Monolithic Microwave Integrated Circuit) used in mobile phones [1].

Chen, Wu and Wu [2] conducted a study on the e-Server for the foundry service, which is a strong point of Taiwan's IC industry. In the study, they presented an e-server framework for foundry service, constructed a system, and applied it to an actual semiconductor process in order to proceed with cooperation in the semiconductor industry. Seddon [3] pointed out that the internet capacity to provide customized service, flexible operation and dynamic capacity allocation had become a key competitive barrier to construct foundry service. Rerick [4] conducted a study on the construction of an MES system for a 6-inch wafer semiconductor plant. In the study, a constraints management technique was used to adjust

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the WIP of the shop floor. Chua, Liu, Wang et al. [5] conducted a study on the determination of the size of the lot release system for the backend assembly of semiconductors. The system has been implemented in actual semiconductor plants by integrating it with the upper systems, including MES and ERP. Sandell and Srinivasan [6] did similar simulation study on the lot release polices particularly for the semiconductor fabrication. Skeith [7] studied the concept of operating a factory at constant WIP via shop floor characteristics curves that provide the relationship between WIP and the production rate. Chen, Tsai, Chang [8] proposed an intelligent MES by integrating manufacturing execution system, data warehouse, online analytical processing and data mining system. They established a three-tiered web-based systematic framework and proved through experimental analysis that the product yield and the manufacturing cycle time all have been improved for the manufacturing industry. Using a distributed object-oriented technique, Cheng, Shen, Deng, Nguyen [9] presented a systematic approach to developing a computer-integrated MES Framework which is open, modularized, distributed, configurable, interoperable, and maintainable. Their MES Framework is designed by the process of constructing an abstract object model based on domain knowledge, partitioning the application domain into components, identifying generic parts among components, defining framework messages, and developing design patterns for generic parts. Such information needs to be supported with a function that gathers the process information generated on the shop floor based on real-time.

Though the compound semiconductor fabrication technologies are similar to the technologies for silicon semiconductor memory devices, production process control technologies tend to rely on the experiences of operators and managers because the production technologies suitable for the characteristics of compound semiconductor fabrication have not yet been sufficiently developed, compared with that of silicon semiconductors. As the conventional method of process information input by paper work depends on the operators' memory and documents, a real-time based response is difficult to implement and the accuracy of the information is degraded [10]. In addition, a production management system is required to respond to the order production and the Open Foundry Service system for inter-business cooperation according to the change to mass customization [11].

In this study, a data acquisition system which is suitable for the production process of compound semiconductors was designed and built by analyzing the characteristics of the compound semiconductor fabrication process. The developed system will enable the keeping of a delivery schedule, a reduction in lead-time, and WIP (Work In Process) adjustment by linking up with the MES (Manufacturing Execution System) and by collecting the process information from raw material input to product delivery in the compound semiconductor manufacturing process. Furthermore, the developed data acquisition system was installed in a compound semiconductor fabrication and its performance was analyzed.

2. Compound semiconductor manufacturing process and foundry service

Though the manufacturing process of compound semiconductors is similar to that of the silicon series memory semiconductor devices, due to the physical properties of the compound (GaAs; gallium & arsenic) and the characteristics of the process, compound semiconductors are difficult to handle and behave irregularly occasionally; they also differ from silicon semiconductors in that both sides of the wafer are processed to form circuits. The photo lithography process, shown in Fig. 1, which is the core process of the compound semiconductor fabrication process, carries out repetitive work in the same process in order to form the desired number of layers required by the device [12].

In a semiconductor manufacturing system, devices are processed and inspected according to unique process information to meet the order or production plan. Fig. 2 illustrates the flow of the compound semiconductor manufacturing process, wherein the production is carried out without a definite pattern [13]. Therefore, the process load varies according to time and the time spent for production also varies. This causes a number of difficulties in the control of

Fig. 1. Core process of the compound semiconductor fabrication.

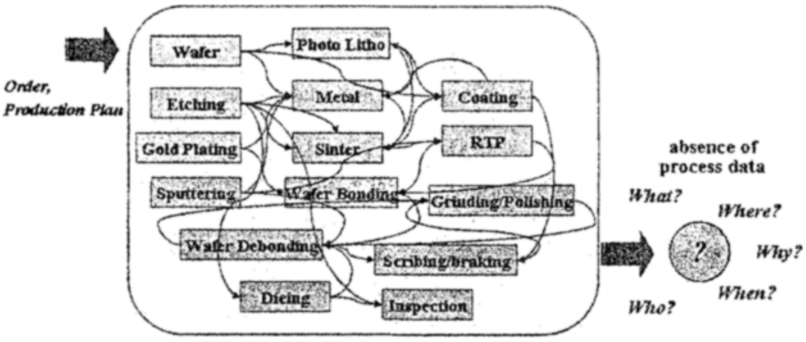

Fig. 2. Manufacturing process flows of compound semiconductors.

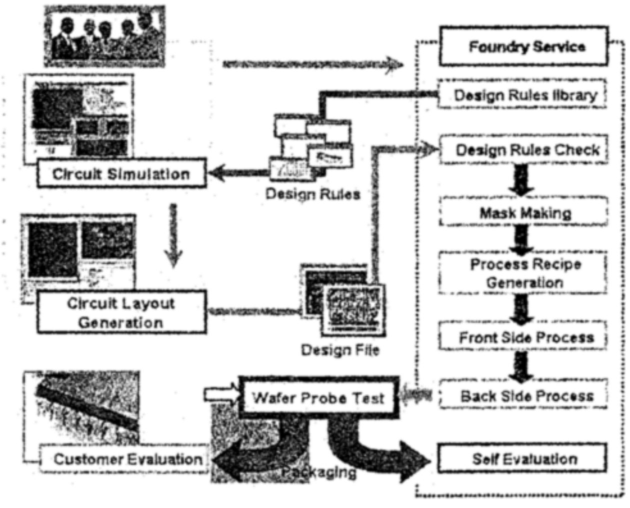

Fig. 3. Foundry service flow of the compound semiconductor manufacturing process.

the production and process information and schedule management between the prior and after processes [14]. For example, a process in the compound semiconductor manufacturing system takes 50 days to complete. Such a process causes problems which have to be resolved by process control technologies or production management according to the characteristics of the process.

If, without a real-time based process information acquisition system in such a complicated production environment, the present status of the process including the location of the ordered product in the process line, load distribution, state of equipment, or delivery date cannot be grasped, then an increase of WIP and an imbalance between the processes, delayed delivery, and productivity degradation will all occur [15].

In the trend of the present semiconductor manufacturing system, semiconductor suppliers mainly carry out design only, while the actual manufacturing processes are carried out by manufacturers with specialized facilities (FAB-line). Such specialization in FABless type manufacturing is referred to as Foundry Service [2].

In the Foundry Service System, the order owner demands more mode-specific information, such as present process status, delivery schedule, quality, process capacity, and facilities statuses, than ordinary order manufacturing systems. And the foundry service provider who can provide such information rapidly and accurately will have an advantage in terms of competitiveness, if on the same quality level. Fig. 3 illustrates the Foundry Service Flow in the compound semiconductor fabrication process. The order owner and service provider conclude an NDA (Non Disclosure Agreement) before placing an order. The order owner designs a product on the basis of the design library which contains the process capacity and facilities of the service provider, hands it over to the service provider who reviews the design for consistency with the rule of the design library and approves it, to be followed by the preparation of mask and actual fabrication. Finished pilot products are inspected jointly by the order owner and the foundry service provider, and then mass production begins.

In order to provide the information required by the order owner in these procedures, a system that can collect diverse information generated in the production site on a real-time basis is necessary.

3. Process information acquisition system

A system for gathering process information in compound semiconductor fabrication was designed and implemented with the following functions. The system should be able to collect the information generated during the manufacturing process and apply it to production and process management on a real time using a paperless technique that excludes job cards. It should also be able to provide the information required by the customers for foundry service on a real time.

Therefore, the developed information gathering system will be characterized by the extraction of process information by recognizing the work information automatically through a bar code attached to the wafer carrier, rather than with a conventional job card, and by the real-time gathering of the process information of equipment without the need for operators to interface with the equipment.

Owing to these features, the reliability of process information can be improved and a real-time based response can be provided against the problems identified by the real-time based monitoring of process information and process control. However, achieving a real-time based response is difficult in terms of the collection of production information on a job card basis precisely because it is not based on real-time practices, in addition to other problems including the increase of WIP (Work in Process) in accordance with the increase in production items.

The manufacturing process of compound semiconductor devices comprises the process level where the actual manufacturing process is carried out and the administration level which places a work order and controls the collected information. At the process level, an information control system was constructed in the server-client system by considering the interface with the equipment and process characteristics in order to collect the process information from diverse sources such as process, equipment, and operators on a real-time basis. However, at the administration level, an information management system was constructed which can administer internally-used information including the process information by product, work instructions and work order, and the information required in the foundry service including the process status, quality, yield rate, etc.

Fig.4 shows the system structure used to collect data on a real-time from the shop floor to meet these requirements. The suggested model comprises a data gathering system targeting various information sources such as the process, equipment, operators,

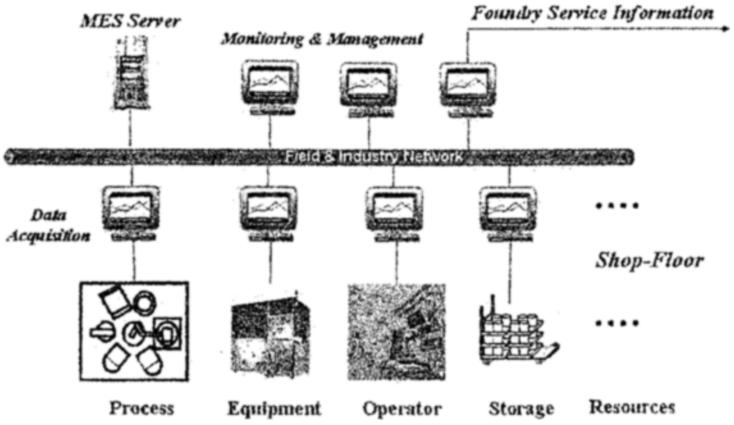

Fig. 4. Structure of data acquisition system.

storage, and so forth, and the monitoring and control of the information. The collected information is stored in the MES server for use in production and process control, and for the provision of the information required by the foundry service.

Regarding the process flow in compound semiconductor plants, it is similar to common processes in that the production lots are derived from the production plan based on the customers' orders; however, a function for gathering detailed process information on the ordered products, which is a characteristic of the foundry services, is required. Fig. 5 illustrates the production process of compound semiconductors.

3.1 Process Information Acquisition by Equipment Interface

Direct interface with equipment can be used to collect accurate process information on a real-time basis. Most semiconductor process equipment uses GEM (Generic Model for Communications and Controls of Semi Equipment) as the standard protocol. As shown in Fig. 6, GEM protocol is connected with the objective Cell Controller via a serial or TCP/IP protocol to monitor equipment status, control, and collect information such as alarm, process program (recipe), error, etc. [16].

The system is characterized by the fact that, while the conventional system makes use of GEM simply at the equipment-level to display the status of the equipment, an additional GEM is built-in on the MES client in order to gather the process information generated in the equipment and transmit it to the MES server, thereby enabling the direct monitoring of equipment information at the DAS client and updating the information at the MES server.

In this study, a process information acquisition system was constructed for the track system, by using the GEM protocol. The track system is one of the key items of equipment in the semiconductor fabrication process, conducting the photo resist coating on wafers [17]. As shown in Fig. 7, the system consists of a coater, developer, adhesion, and hot & cool plate, transfers the wafer automatically using two linear robots, and is able to handle four units simultaneously. It can conduct processing or inspection using a set-up recipe which can be transmitted from outside.

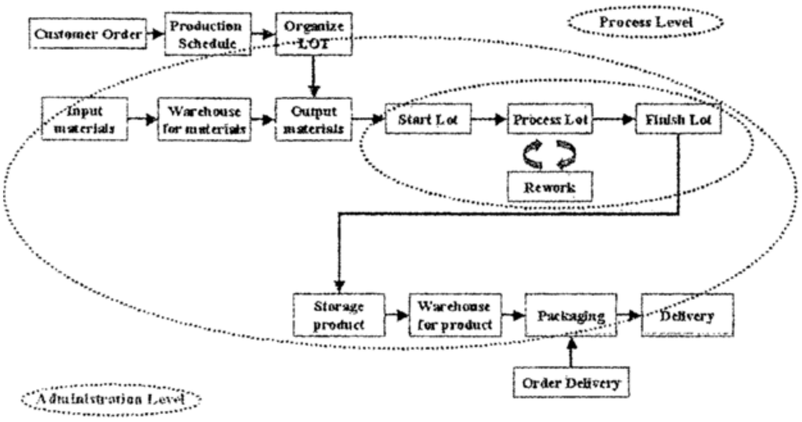

Fig. 5. Manufacturing process for compound semiconductors.

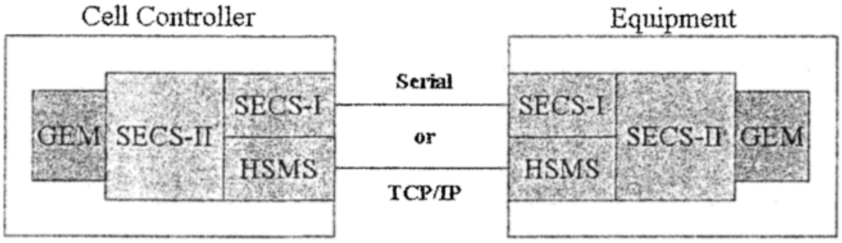

Fig. 6. Process information acquisition via direct Interface with process equipment.

Fig. 8 shows the track system configuration for collecting process information. The cell controller of the track system is connected to the network, and the client for process information collection is connected with the network too. These conduct the control and monitoring of the track system by using the HSMS (TCP/IP) provided by the GEM protocol.

The DAS client reads the Lot No. on the wafer carrier cassette and requests the cell controller for ration. Once prepared, the track system begins work at an available bay. During the operation, the cell controller transmits the process information requested by the DAS client in message form. The transmitted information includes the Lot No., Slot No., beginning and ending time, and beginning and ending temperatures of the hot & cool plate, etc. Fig. 9 illustrates the communication sequence carried out by the DAS client and the cell controller of the track system on the

Fig. 7. Track system configuration.

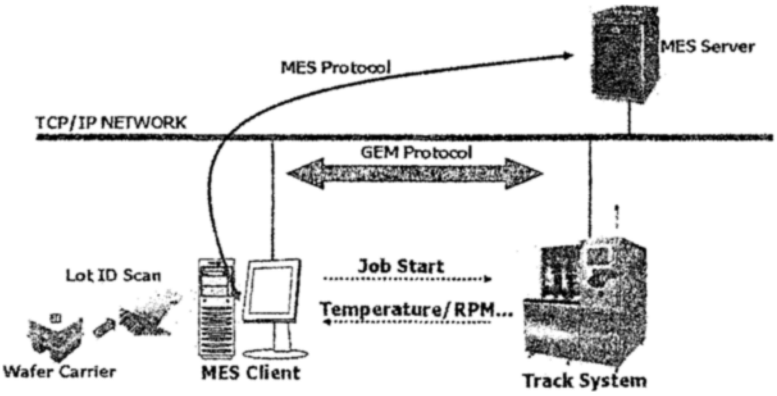

Fig. 8. Process information collection of track system using GEM protocol.

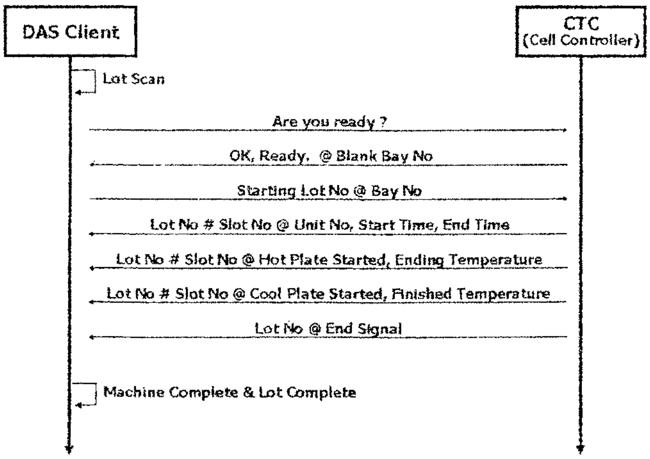

Fig. 9. Communication sequence between the DAS client and cell controller.

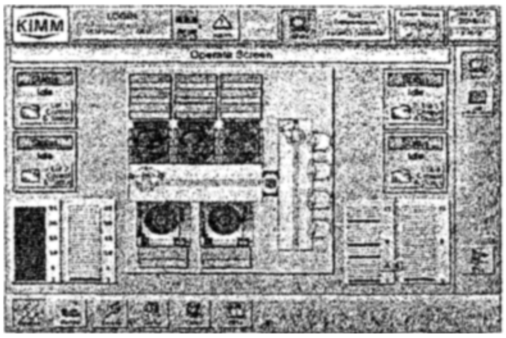

Fig. 10. Track system monitoring window on DAS client.

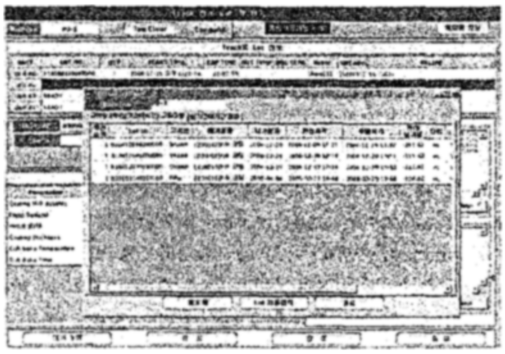

Fig. 11. Lot start and completion in the track system (waiting lot inquiry).

GEM protocol.

Fig. 10 shows a monitoring window of the track system operated in the cell controller of the track system. In this window, the lot status, the data required for process information management, which are the step being processed, processing temperature, RPM, the recipe in use in the track system are monitored and collected.

In the DAS client, the work start command is given to the track system by entering the Lot No. with which the work will begin. Fig. 11 shows an inquiry window for the lots waiting in the track system. The window displays the characteristics (waiting process, delivery schedule, order owner, planned and input time of the lot, etc.) of each lot and the lot organization information.

3.2 *Process information acquisition by the operator input method*

Not all semiconductor process equipment has a built-in standard communication protocol such as GEM. While even without GEM, the automation of information collection can be implemented with other interface works, by taking into consideration the economic aspects and the fact that some information is entered by the operators in addition to the process information from the equipment, a process information acquisition method by keystroke was developed.

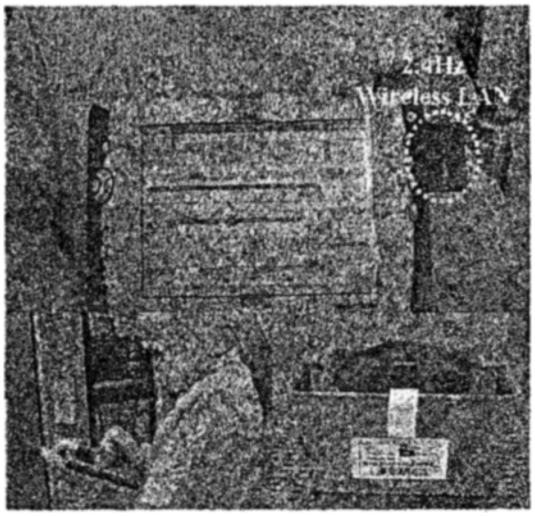

Fig. 12. Tablet of operator keystroke type for process information acquisition.

Given the characteristics of the compound semiconductor fabrication process and the convenience of information input by the operators, the smart tablet shown in Fig. 12 was selected for the input tool of process information. The smart tablet, which uses manufacturing equipment and all the processes, is both mobile and capable of process information collection and processing information such as work instructions. Lot information is entered with a bar-code scanner, and operators can carry out paperless works using the touch panel on the smart tablet. In particular, as a large amount of equipment and devices are used in the semiconductor process, the 2.4GHz bandwidth was used for communication in consideration of the electromagnetic interference from wireless LAN.

All the processes consist of process wait, in process, and wait after process completion. As the information from the process is generated by the Lot No. unit, the moment of selecting a Lot No. in a specific process is the time when process wait is completed. Operators enter process information via the DAS client input window. Once the process has been completed, the process results and inspection information are entered by lot (wafer mapping). As the inquiry and input of process information are in a layered scheme, so proc-

Fig. 13. Wafer process results, inspection, reject input window.

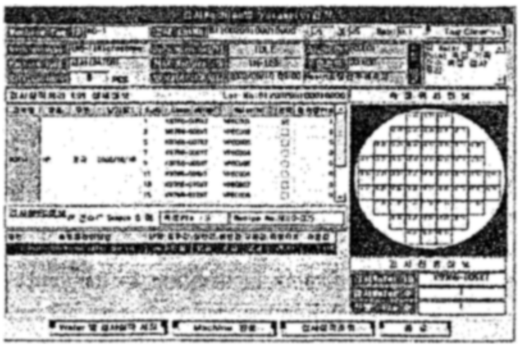

Fig. 14. Parameter results by inspection machine.

ess information and inspection results by wafer can be entered on the basis of the lot organization data. Fig. 13 shows the input window for the process results, particle inspection information and rejects information when the process is finished. Fig. 14 shows the window for handling the inspection result information by inspection machines.

4. Application on real fabrication

The developed system was implemented in a compound semiconductor plant to verify its effectiveness. The plant has the major production items of LED and MMIC by 7:3 ratios for orders and planned production, respectively. The process varies according to product type and order. The process of a compound semiconductor consists of six bays from bare wafer feed to inspection.

At the management level, the design, production, process control and sales departments should share related information on the basis of the data collected from the work site and provide customers with the information required for the foundry service. The information management system was designed on a Web-basis for information sharing and management efficiency. The management level system was constructed with wide classification functions including basic information management, production plan, material management, process management, shipping control, defects report, equipment management, production efficiency management (gathering), production progress management (real-time based), and other sub-functionalities.

Fig. 15. Scheme for issuing new work order and searching issued work order.

Fig. 15 shows a scheme for consulting the work orders issued by the production planning function and the issuance of new work orders. Lots are organized and input into the process with reference to the issued work order, and the information is collected and controlled on a real-time basis with reference to the product number of the lot. Consequently, inquiries about all the information generated from the classified lot in the process, including process time, equipment, inspection report by process, operators, transfer and waiting, and so on, can be made.

Fig. 16 shows an inquiry about the lot tracking information of the monitoring function. In an application lasting about four months, the real-time timeliness of the data was measured to be less than 1 second, and analysis showed that the reliability had been enhanced. As regards the production control features, the cycle time had been reduced and the shipping schedule had been adhered to with greater precision.

5. Conclusion

The semiconductor industry is being restructured as a mass customization production system and foundry service, and hence requires a system that corresponds

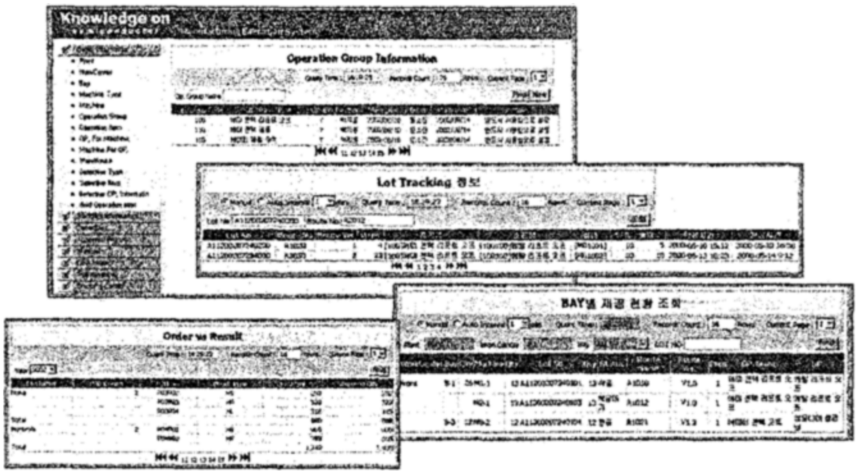

Fig. 16. Monitoring of lot tracking and inquiring of stock in shop floor.

to the foundry service by inter-business cooperation. In order to respond to such a trend positively, production-related information systems and the provision of accurate process information to such systems are required.

In this study, a real-time based paperless process information acquisition system was developed and implemented at the work site of a compound semiconductor manufacturing fabrication. The system is capable of processing the information directly from the process equipment and operators' keystroke input. When compared with a conventional paper work-using process information processing system, the new system showed a 95% or better confidence level in terms of process information and the real-time timeliness of the data was analyzed to be within 1 second. The following is a brief description of the effects of the system after implementation.

1) The system was stabilized, reducing the production cycle time from 8 to 6 weeks.

2) 50% or more of the work preparation time was saved due to the sharing of process information and the efficiency of data usage.

3) The orders were increased due to the accurate analysis of the process status. The delivery schedule meeting rate was improved.

4) The yield rate of the wafer was improved from 70% to approximately 80%. The confidence level of the process information and quality information was more than 95%, enabling a response to the trend of the foundry service system and inter-business cooperation.

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