e-Manufacturing System for Next-generation Semiconductor Production

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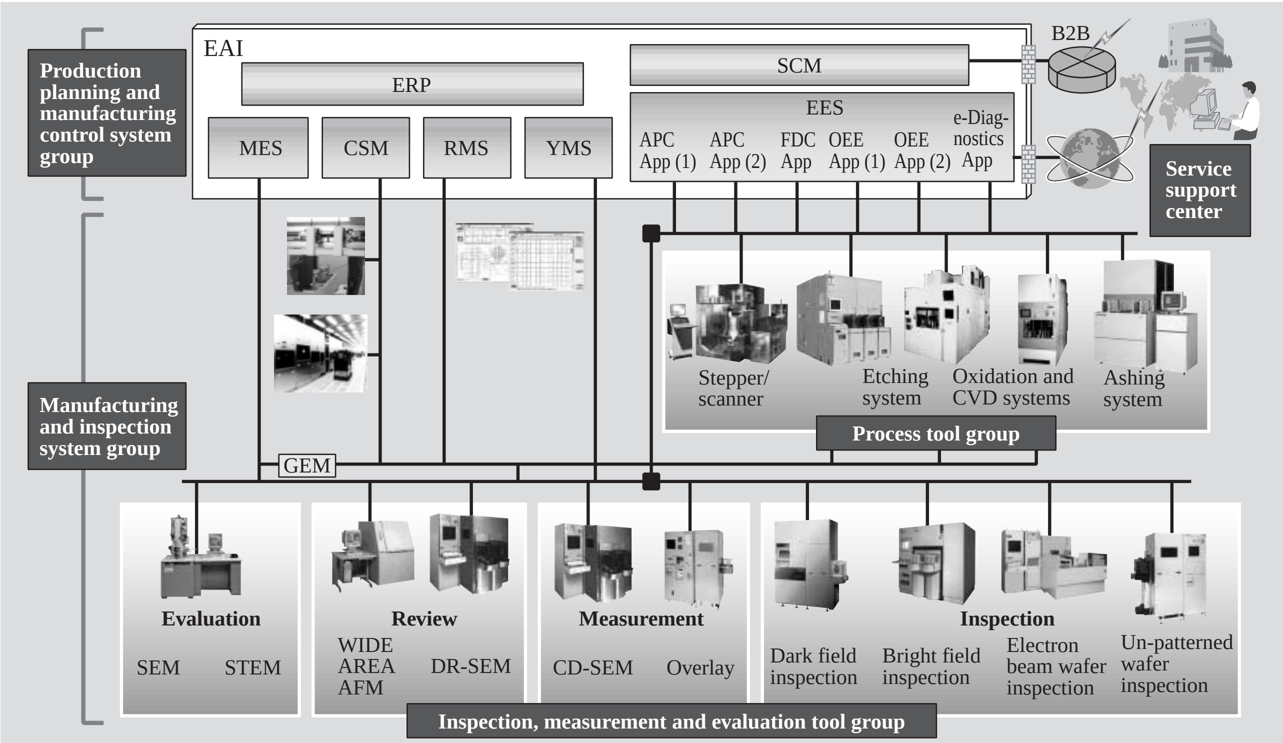
OVERVIEW: Next-generation semiconductor factories need to support miniaturization below 100 nm and have higher production efficiency, mainly of 300-mm-diameter wafers. Particularly to reduce the price of semiconductor devices, shorten development time [thereby reducing the TAT (turn-around time)], and support frequent product changeovers, semiconductor manufacturers must enhance the productivity of their systems. To meet these requirements, Hitachi proposes solutions that will support e-manufacturing on the next-generation semiconductor production line (see Fig. 1).

INTRODUCTION

THE semiconductor and electronic part industries currently face two major challenges: implementing IT-based structural reform and improving profitability. The establishment of IT-based "e-business" and "e-manufacturing" is drawing much attention as a way to improve on the development and equipment investment that put negative impact on profitability.



EAI: enterprise application integration
CSM: carrier system management
SCM: supply chain management
FDC: fault detection and classification
B2B: business to business
SEM: scanning electron microscope
DR-SEM: defect review SEM
ERP: enterprise resource planning
RMS: recipe management system
APC: advanced process control
e-Diagnostics: remote diagnosis
GEM: generic equipment model
STEM: scanning transmission electron microscope
CD-SEM: critical dimension SEM
MES: manufacturing execution system
YMS: yield management system
APP: application
OEE: overall equipment effectiveness
CVD: chemical vapor deposition
AFM: atomic force microscope

Fig. 1—Overall Configuration of e-Manufacturing Proposed by Hitachi for Next-generation Semiconductor Production Line.
In e-manufacturing on the next-generation semiconductor production line, a production planning and manufacturing control system group, a manufacturing and inspection system group, and a service support center should be linked using IT (information technology) for efficient utilization of information in order to enhance productivity.

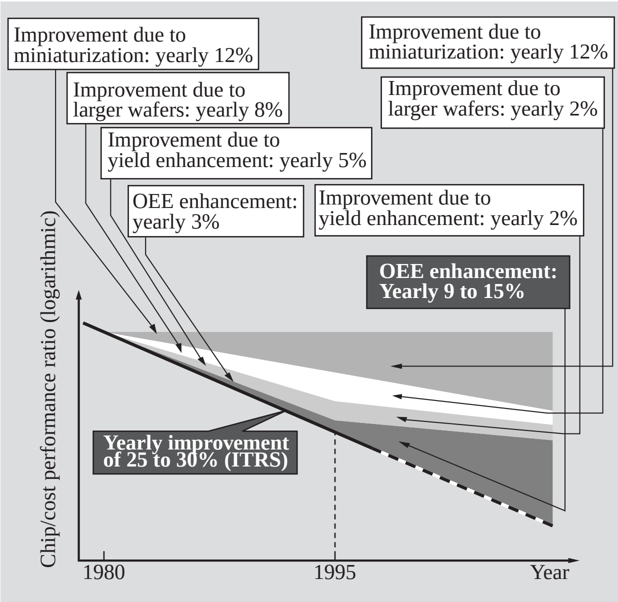


Fig. 2—Reduction in Cost/Performance Ratio of Semiconductor Chips.
Reduction in the chip/cost performance ratio requires an annual increase in the OEE of 9 to 15%.

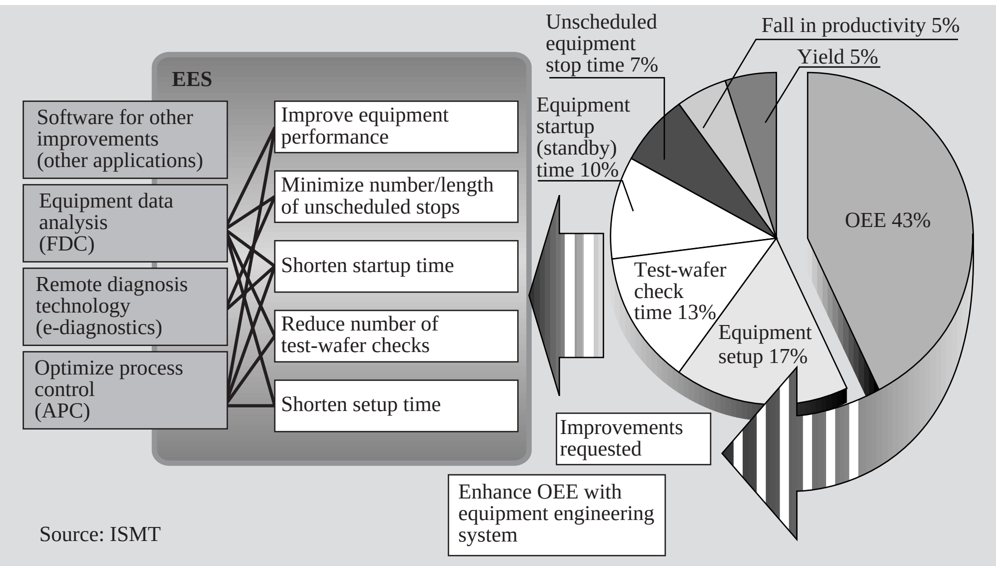
The trend in the cost/performance ratio of semiconductor chips is illustrated in Fig. 2. Device miniaturization and the increase in the number of obtainable chips due to larger diameter wafers have contributed to reducing the ratio. Performance enhancement through device miniaturization will continue according to the International Technology Roadmap for Semiconductors (ITRS). On the other hand, the introduction of larger diameter wafers, particularly the recent advent of 300-mm wafers, has substantially increased the investment needed in equipment investment. Moreover, the increase in the size of the process and transfer equipment and the introduction of single-wafer processing has complicated the equipment design process.

Enhancing the yield has been the focus of process control improvement over the last ten years. Enhancement has been achieved by continually improving the equipment used for measurement, inspection, and analysis/evaluation. Up to about ten years ago, the inspection system for process control accounted for about 5% of the total investment in chip manufacturing equipment. The ratio is now between 10 and 20%. Moreover, the adoption of higher sensitivity inspection systems has increased data output, which has increased analysis time and thus production costs. Thus, the introduction of inspection systems, whose original objective was to lower the chip cost/performance ratio, had the opposite effect of raising cost. To reduce the chip cost/performance ratio even more, attention is now turning to improving the utilization efficiency of the manufacturing equipment, i.e., OEE (overall equipment effectiveness).

Fig. 3 shows how semiconductor manufacturers currently utilize their equipment (based on actual operation) and the improvements requested. As shown in the chart, OEE is only about 43%, meaning that more than half the time the equipment is not contributing to actual production.

As shown by the chart in Fig. 3, a major factor in the reduced OEE is the length of time spent to set up the equipment. This includes the time spent determining whether the previous process was performed properly and changing the processing parameters. Another major factor is checking by test wafers. This includes a preliminary check of particle

Fig. 3—Current Utilization of Equipment (Actual Operation) by Semiconductor Manufacturers and Improvements Requested. An EES (equipment engineering system) that optimizes process control and provides remote diagnostics is needed to increase OEE.



generation in the process equipment and optimization of the exposure conditions, i.e., “trial exposure.” These conditions have normally been optimized in the development stage, and in future microlithography, process tolerances will be much smaller, and more time will be needed for optimizing them due to mechanical differences between process devices. At the same time, reducing equipment startup (standby) time and unscheduled equipment stop time require a person with process knowhow and expertise in equipment control techniques, which places an additional burden on the operator.

An EES (equipment engineering system) would help improve all the above factors because it would acquire, analyze, and optimize the process data and working status data of the equipment. Specifically, an EES has a database for storing the diverse and voluminous data obtained from the equipment and functions that use this data for APC (advanced process control), e-diagnostics, and FDC (fault detection and classification).

This paper describes the optimum process control technology and e-diagnostics developed by Hitachi as core technologies supporting e-manufacturing and their expanded use in the future.

TECHNOLOGIES SUPPORTING e-MANUFACTURING

Device miniaturization is narrowing the error range allowed in each chip-manufacturing process. Variations that used to be allowed are now affecting device characteristics significantly or even causing defects. Two technologies have been developed to overcome this problem: APC and e-diagnostics. APC controls the processes so as to minimize unevenness and variations in accuracy due to differing process conditions, device specifications, wafer states, etc., thereby stabilizing device quality. e-diagnostics reduces maintenance costs and supports preventive maintenance by enabling manufacturing equipment to be diagnosed on-site via the Internet. This means that an authorized service technician can access and diagnose production equipment without having to first travel to the location, thereby saving time and money.

Advanced Process Control in Lithography Process

Fig. 4 illustrates the application of the ARGUS* APC to a lithography process composed of multiple exposure systems and a resist coating/developing system called “Track.” To maintain process normalcy, an overlay error measuring system called “Overlay” and a CD measuring CD-SEM play important roles.

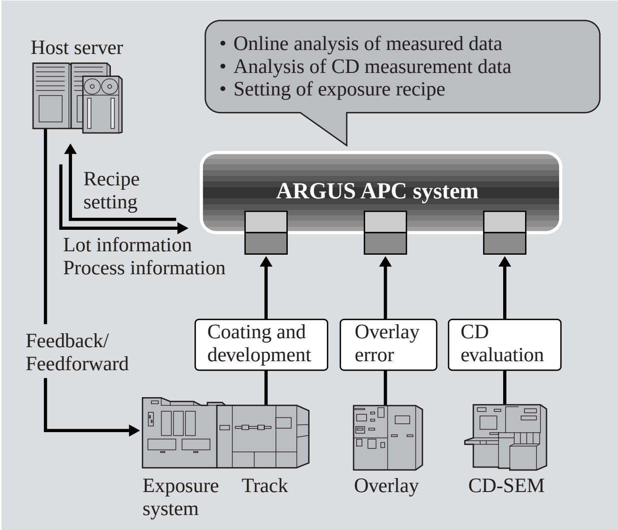


Fig. 4—Application of ARGUS APC to Lithography Process.
ARGUS detects and analyzes changes after each process completes and corrects the processing recipe as required to stabilize the process.

Hitachi as a CD-SEM and Overlay maker/supplier has been tracking the needs for inspection control of the lithography process as expressed by many customers/users and working to stabilize the process. Based on the knowledge and information it has obtained, Hitachi developed the ARGUS APC system in collaboration with New Vision Systems. ARGUS is an integrated system that monitors changes in a process while gathering data from such measuring systems as Overlay and CD-SEM and performs run-to-run control (i.e., feedback and feedforward at each process execution) of the process equipment. ARGUS minimizes process variations by detecting and analyzing the changes after each process and then correcting the processing recipe as required.

Most APC software makers provide only a framework, while content, i.e., the data analysis and control programs, are generated by the users themselves. In contrast, ARGUS includes functions for data analysis and process control.

Furthermore, ARGUS incorporates a highly accurate analysis function suitable for many-kinds and small-lot manufacturers, so it enhances overall equipment effectiveness and reduces turnaround time. Costs should be reduced substantially due to decreases in the number of leading wafers and the rework (regeneration) ratio.

*: ARGUS is a registered trademark of New Vision Systems.

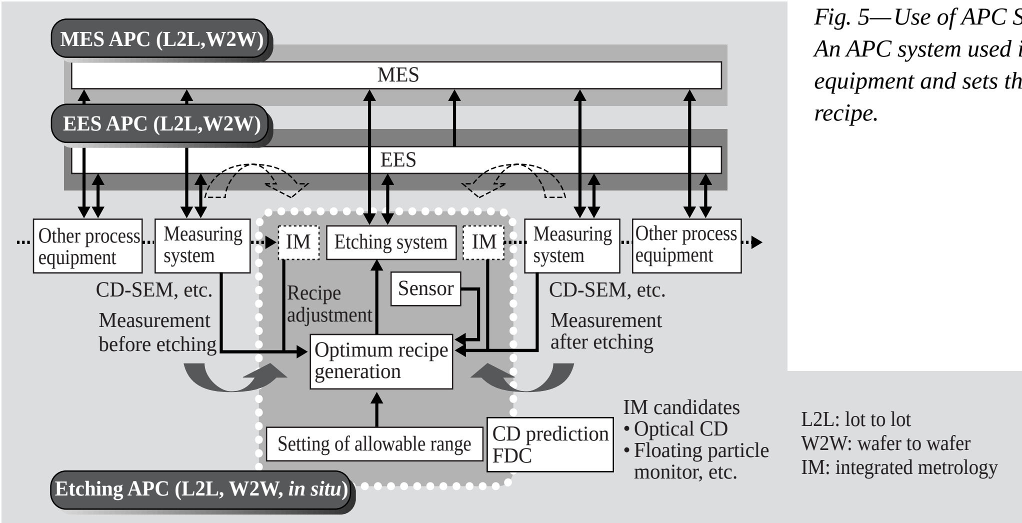


Fig. 5—Use of APC System in Etching Process.
An APC system used in etching monitors the equipment and sets the optimum processing recipe.

Use of Advanced Process Control in Etching Process

Fig. 5 illustrates the use of APC for equipment monitoring and optimum processing recipe control in the etching process.

In the etching process, etching must be carried out exactly as specified along with progress in miniaturization and diversified small-quantity production. This means setting the optimum process conditions for not only variations due to equipment, but also those attributable to equipment other than the etching equipment. To meet this requirement, Hitachi has initiated monitoring of process performance variations in the etching equipment and a basic examination of control technologies ahead of its competitors. Hitachi has been advancing the development of diverse APC-related technologies in search of higher-level APC for the etching process. They include various sensor and analytical technologies for exact in situ monitoring of process performance and status, various control technologies such as run-to-run control, integrated metrology for incorporating an optical CD measurement system or the like into the etching system, and data extraction and networking technologies for data linking with a CD-SEM.

Among the technologies being developed is integrated metrology for integrating various inspection systems with the process equipment. This will result in several improvements.

(1) Enhanced net equipment operating ratio and operator efficiency, because in-line and in situ QC (quality control) are possible in wafer-to-wafer production.

(2) Improved process control accuracy, because the status of the equipment can be checked before, after, and during processing.

(3) Better quality control accuracy than with a standalone process control tool, because the QC will be faster and cover all wafers.

Hitachi will continue improving the controllability of the etching process by integrating the floating particle monitor for real-time measurement of particle movement around the wafer during etching and an optical CD measurement system for measuring the film thickness on the wafer surface as well as the wafer's physical shape and dimensions, etc.

e-Diagnostics

e-diagnostics enables a distant repair technician to start up, diagnose, and repair equipment, resulting in (1) a shortened MTTR (mean time to repair), (2) an increase in the equipment operating ratio, and (3) a reduction in equipment maintenance costs (including personnel expenses).

In response to the needs of leading device makers for e-diagnostics, ISMT has been releasing a series of guidelines on e-diagnostics. Hitachi has taken the lead in responding to these needs.

A list of device makers' concerns about e-diagnostics is given in Fig. 6 along with the corresponding countermeasures available from Hitachi. In e-diagnostics, equipment is accessed from outside a device maker's site via the Internet. Therefore, device makers worry about leakage of confidential manufacturing data, adverse effects on the manufacturing process, falsification of maintenance histories, etc. To prevent these problems, Hitachi has developed such innovative techniques as a digital certificate and two-element user authentication,

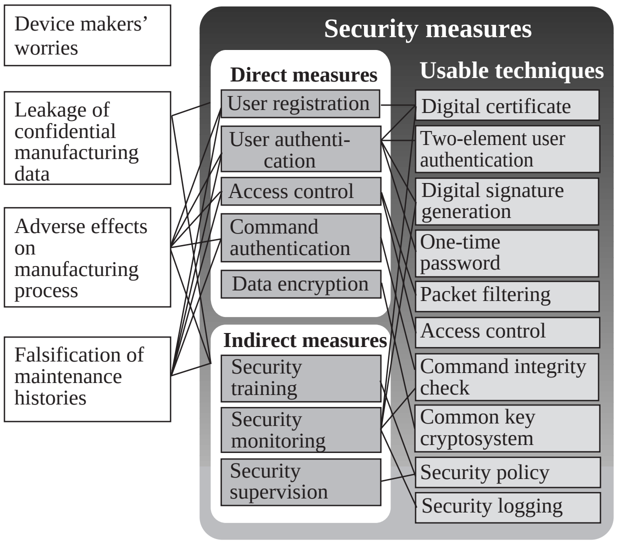


Fig. 6—Security Concerns with e-diagnostics and Hitachi Countermeasures.
In e-diagnostics, device makers' confidential data and manufacturing processes can be protected by security measures.

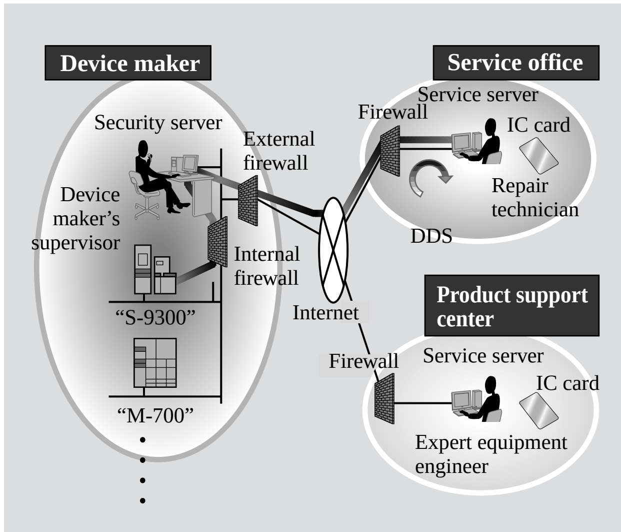


Fig. 7—Example Application of e-diagnostics.
Shown here is an example application of e-diagnostics in which a device maker, service office, and product support center are interlinked.

thereby ensuring data security.

An example e-diagnostics application is illustrated in Fig. 7. The equipment at a device maker's site is connected with a server at a service office. The connection is protected by a security server and two firewalls. Additional security is provided by issuing an IC card to each user. Once a secure connection is established, data acquisition, transmission, and analysis are carried out using a fault analysis system in which a rich variety of information is accumulated and using troubleshooting software such as defect part diagnostics support. Using the information obtained, the technician can determine the status of a device and identify the problems to be corrected.

TRANSITION FROM EQUIPMENT BUSINESS TO SOLUTION BUSINESS

Fig. 8 illustrates Hitachi's general scheme for a next-generation semiconductor factory and the range of e-manufacturing applications. Hitachi has been

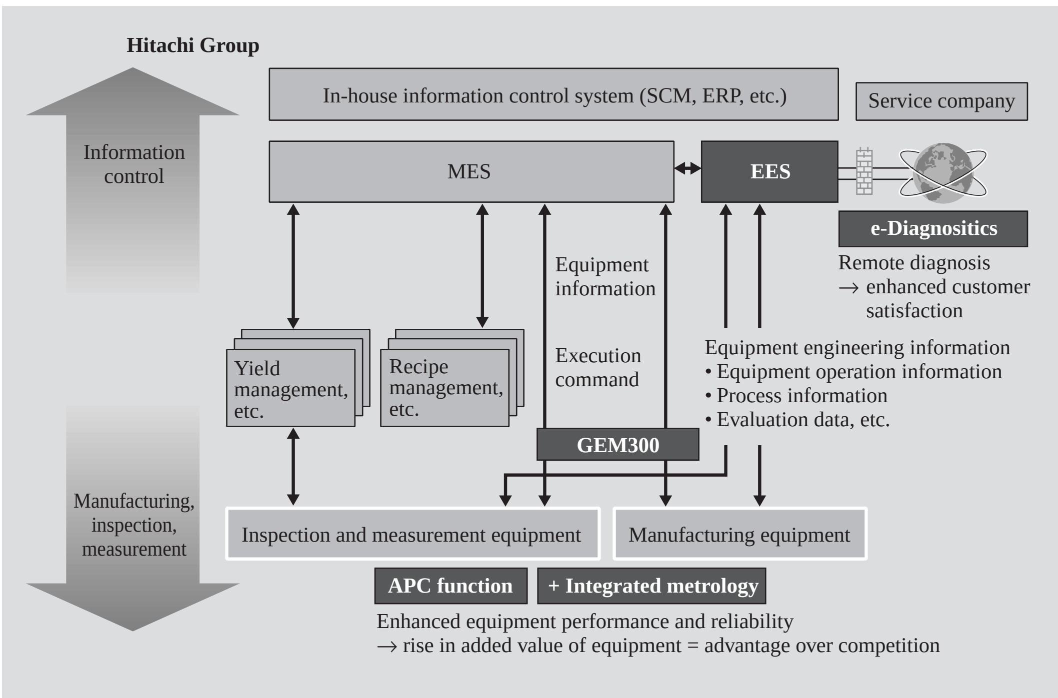


Fig. 8—General Scheme for Next-generation Semiconductor Factory and Range of e-manufacturing Applications.
From a broad range of solutions, from leading-edge manufacturing equipment to high-level (information-control) systems, the best solutions will be provided in response to customers' needs.

providing products and systems such as inspection/measurement and manufacturing equipment and yield-enhancement support systems that provide functions and performance matching user requirements. However, customers are now looking for ways to enhance the overall effectiveness of their equipment and reduce chip costs. Responding to this as an equipment supplier, Hitachi has been establishing a business concept and a supply system for presenting the best solutions in e-manufacturing to our customers.

To provide the solutions needed by our customers to implement and support e-manufacturing, we need to switch from being a conventional equipment business to being a "solution business." We are thus working on APC technologies for improving equipment performance and reliability, e-diagnostics systems for enhancing equipment maintenance and servicing, and equipment engineering systems for organically linking and executing APC with e-diagnostics and similar innovations.

Hitachi has the technological capacity to provide the constituent elements of e-manufacturing (information control system group and equipment/system group) as a business and the functions (equipment engineering system, APC, e-diagnostics, etc.) as shown in Fig. 8. By harnessing the synergy between its product and engineering capabilities, Hitachi will be able to offer the best solutions, from leading-edge manufacturing equipment to high-level systems, to our customers.

CONCLUSIONS

We have described advanced process control and e-diagnostics technologies and their expansion to business in the years to come.

Semiconductor-related associations, mainly in Japan and the U.S., are conducting a variety of workshops and undertaking standardization activities for e-manufacturing. Thus, a next-generation semiconductor factory based on e-manufacturing is taking shape.

Hitachi is participating in these activities and helping to popularize e-manufacturing in the electronic parts industry.

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