Clean-room Technologies for the Mini-environment Age

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OVERVIEW: To improve quality and production yield of various electronic devices (such as semiconductors, displays, and storage media), it is necessary to ensure a precisely controlled environment in which cleanliness, temperature and so on are controlled in accordance with the needs of the fabrication process. In recent years, the trend for advanced environmental control of the minimum required clean-room space only has become more pronounced. Accordingly, in line with this trend, Hitachi Group has been developing clean-room technologies from the viewpoints of both large-space (i.e. "ballroom-type") and localized clean-room environments. As "total clean technologies" to satisfy various requirements, several technologies are described in this paper. That is to say, to handle ballroom-type environments, a "return-ductless" clean room (which has relaxed cleanliness and good floor-space efficiency) is provided. Moreover, to handle localized-type precision environments, technologies such as systems for not only efficiently eliminating particulate contamination as a matter of course but also molecular contamination like various chemicals and water molecules (namely, a "chemical-free environmental system" and a "low-dew-point environmental system") and high-precision temperature-control systems are being provided.

INTRODUCTION

CLEAN-ROOM technologies have changed from whole-area down-flow systems, which make all areas high-cleanliness ones, to "localized" cleaning environments by means of "mini environments"—namely, an enclosed, local clean environment [1],[2] (see Fig. 1). A classic example of this shift is a semiconductor fabrication plant for 300-mm-diameter wafers, where

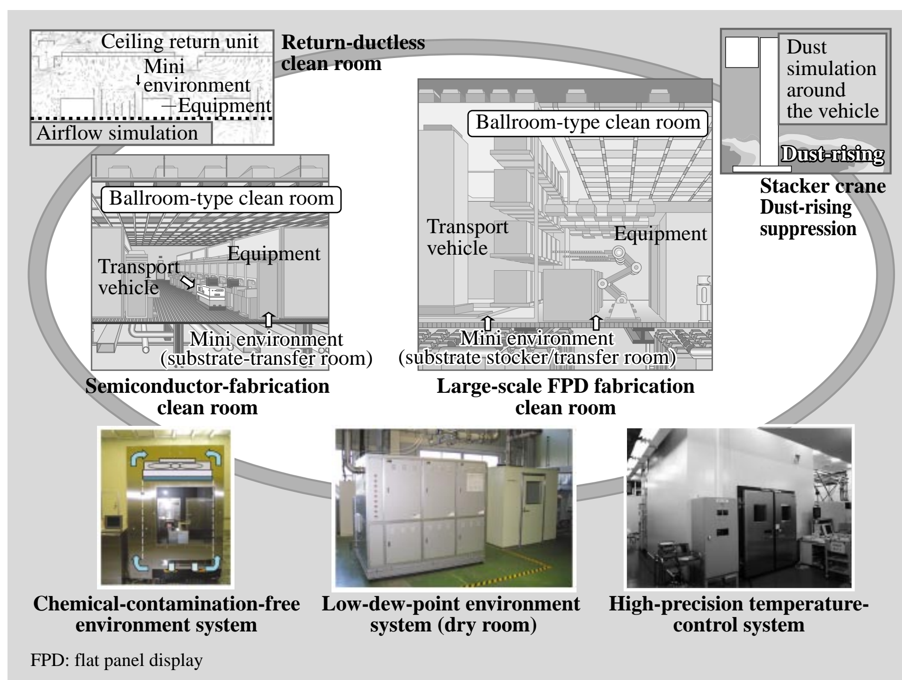

Fig. 1—Ballroom-type Clean-room Technology and Localized High-precision Environmental System Technology.
As clean-room technologies for the mini-environment-system era, ballroom-type clean rooms (with outstanding energy-saving and cost performance) and various systems enabling localized precision environmental control of fabrication processing are being provided.

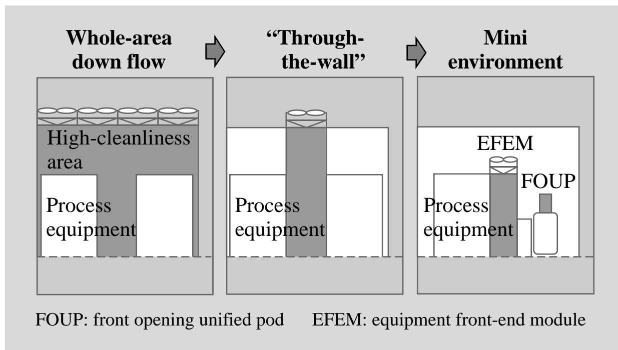

Fig. 2—Trend of Clean Rooms.
Localized cleaning in a "mini environment" is becoming mainstream.

wafers are placed in FOUPs (front opening unified pods) and conveyed. Moreover, by environmentally controlling the space for transferring wafers from the FOUP to various equipment—namely, a mini environment called an EFEM (equipment front-end module), a wafer can be processed without exposure to a direct clean-room environment (see Fig. 2). Consequently, it is very important to implement advanced cleaning focused on this mini environment and to moderate the environment of an entire clean room to the level required for equipment maintenance to reduce costs and save energy. Given this background, the present paper describes methods developed for clean-room technologies for handling the era of "local cleaning" in such a mini environment.

NEEDS OF "LOCAL-CLEANING" CLEAN ROOM

Beginning with semiconductors and now including FPDs (flat panel displays), HDDs (hard disk drives) and their respective materials, industrial fields that need a clean environment are spreading more than ever, and the demands for clean fabrication environments are growing stronger and stronger as performance improvement and miniaturization of devices continue. The detailed requirements regarding fabrication environments for semiconductors are designated in the ITRS (International Technology Roadmap for Semiconductors)[(3)]. Some values abstracted from the ITRS are listed in Table 1. It is well understood that as process dimensions are scaled down, the size of contamination particles that should be controlled also becomes smaller, and measures against chemical contamination on the molecular level become essential. In addition, in regards to the environment for processes like lithography, stricter desired values are being specified at great length. As regards the cleanliness of

TABLE 1. Requirements Regarding Environment for Fabrication of Semiconductors (abstracted from ITRS 2005)
As the overall cleanliness of the whole clean room is relaxed, in line with the miniaturization of devices, even better cleaning inside a "mini environment" (i.e. the environment directly around the wafer) is needed.

	2007	2010	2015
• Device Minimum feature size	65 nm	45 nm	25 nm
• Clean-room-environment control Smallest particle size that must be controlled	33 nm	23 nm	13 nm
Cleanliness of entire clean room	ISO class*6	ISO class 6	ISO class 7
Local cleanliness of mini environment	ISO class 2	ISO class 1	ISO class 1
Chemical contamination (in gas phase)			
Acid (SO_4)	1,000 pptM	500 pptM	500 pptM
Base (NH_3)	5,000 pptM	2,500 pptM	2,500 pptM
Condensable organics	3,000 pptM	2,500 pptM	2,500 pptM
Chemical contamination (wafer surface deposition limit) Condensable organics (one-day-exposed surface)	2 ng/cm^2	0.5 ng/cm^2	0.5 ng/cm^2

ITRS: International Technology Roadmap for Semiconductors
ISO: International Organization for Standardization
* ISO class is expressed in number of particles of more than 0.1 µm in an atmosphere of 1 m^3 as powers below the 10th power. For example, class 1 of the Federal Standard being applied conventionally is equivalent to ISO class 3, and class 1000 to ISO class 6.

clean rooms, on the one hand, in the mini environment directly surrounding a wafer, more advanced cleaning—namely, from level-2 class to level-1 class specified by the ISO (International Organization for Standardization)—is being demanded; on the other hand, the specified cleanliness of the entire clean room is being relaxed from the present class 6 to class 7 after 2012 and class 8 after 2019 as it approaches that of a general-room environment. Thus, as for constructing a clean room, it is being proposed that a more advanced mini environment should be realized within a low-purity ballroom-type-clean-room environment.

As clean-room technologies to meet the above-described demands, "return-ductless" clean rooms (with a good area efficiency in regards to "ballroom-type" clean rooms) and various systems—such as chemical-free-environment systems (which can reduce chemical contamination in a local, high-precision environment by one digit compared to levels achieved up till now), low-dew-point environment systems (which reduce adverse effects of moisture on coatings and films), and high-precision temperature-control systems for precise processing and measurement—have been developed.

BALLROOM-TYPE CLEAN-ROOM TECHNOLOGY AND LOCAL-PRECISION-ENVIRONMENT SYSTEM TECHNOLOGY

Good-area-efficiency Ballroom-type Clean Rooms

The airflow-cycling system of a ballroom-type clean room consists of a cycle in which clean air blown from an FFU (fan filter unit) on the ceiling surface is returned to a ceiling chamber via a return duct. This return duct takes up about 10% of the floor space of a clean room. Given these circumstances, Hitachi Group has developed a "return-ductless" clean room—which satisfies requirements for cleanliness and temperature distribution without using return ducts (see Fig. 3).

In regards to this system, to cut off the path that short-circuits the airflow blown from the FFUs on the ceiling to the ceiling return unit, "eyelid" structures were set up with good effect. In addition, the position of the "mini environment" is arranged apart from the ceiling return unit so that airflow from the FFU on the ceiling surface is drawn in by the FFU of the mini environment and thereby guided down to the under-floor area.

As a result of returning the rising airflow to the ceiling return unit via the maintenance area on the equipment rear side, it was possible to configure an airflow circulation system including under-floor ventilation. Moreover, a dry coil for heat processing in the room is set up between the ceiling-return unit and the ceiling chamber, thereby enabling equivalent room-temperature control as conventionally possible. Analysis by airflow simulation confirmed that this environment could be maintained throughout an entire clean room and that this return-ductless clean-room technology can be applied to semiconductor mass production of cutting-edge 300-mm-diameter wafers[4].

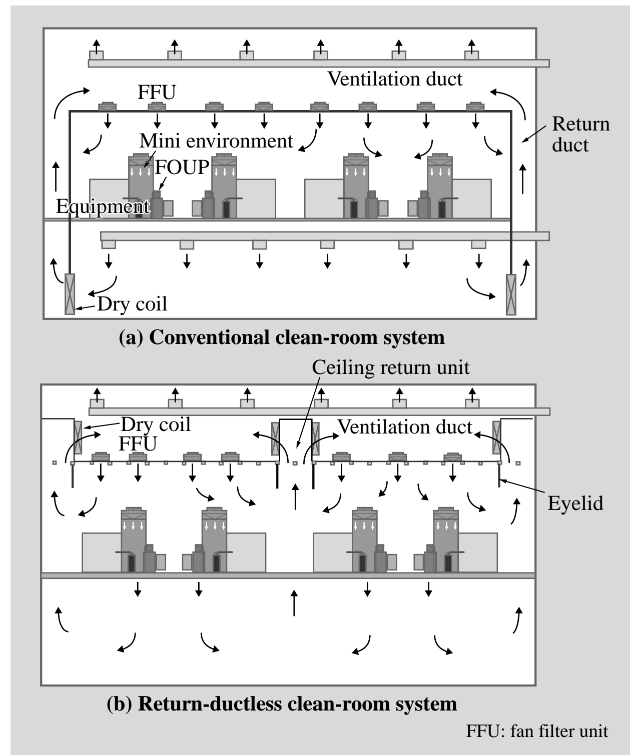

Fig. 3—Comparison of Return-ductless Clean Room and Conventional Clean Room.
By assuring airflow circulation of the entire clean room, even without return ducts, the available floor space can be improved by about 10%.

Chemical-free-environment System

As a mini environment for realizing better cleaning under a low-purity surrounding environment, an air-flow-circulation chemical-free chamber was developed. An example application of this chamber to EFEM—a device for transferring wafers from an FOUP to processing equipment—is shown in Fig. 4. In the case of a conventional method, air cleaned by the FFU (attached to the upper part of the EFEM chamber) and the chemical filter is channeled into the EFEM and then completely discharged. On the other hand, in the case of the airflow-circulation method, the airflow ventilation is set up in the form of a circulation path of air within the EFEM in order to re-use the discharged clean air. As a result of this airflow circulation, effects such as further reduction of chemical-contamination concentration in the EFEM, life extension of the chemical filter, and suppression of discharge of dust generated by the drive parts of

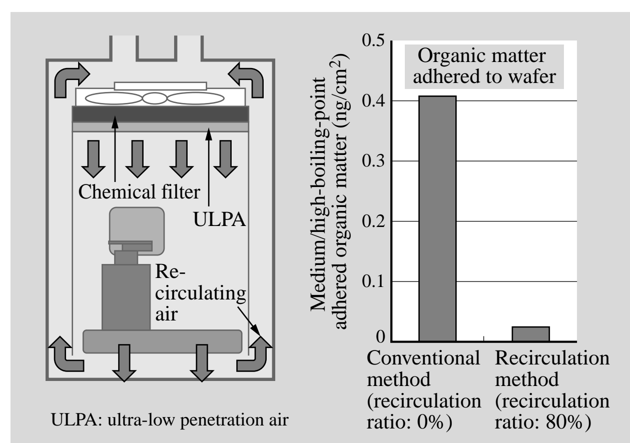

Fig. 4—Airflow-circulation-type Chemical-free Chamber.
By using a method of circulating airflow in a mini environment fitted with a chemical filter, chemical-contamination level can be reduced by a single digit.

the EFEM are obtained.

In fact, measurement results showed that in the interior of the EFEM (whose circulation rate is taken as 80%), air-borne contamination concentration and wafer-adhered contamination were less than one tenth of that attainable with a conventional system (circulation rate of zero)—even though with the same organic-matter-removal chemical filter was used(5). The developed system creates a mini environment for equipment requiring a particularly clean wafer environment (such as thin-film processing and measurement devices).

Low-dew-point Environment System

A dry room for supplying air to areas that need a low-dew-point atmosphere generated by a desiccant-type dehumidifier is shown schematically in Fig. 5. This is a system for providing an environment for fabricating and storing manufactured products that suffer the problem of quality deterioration due to moisture. In this system, circulating processing air through a dehumidifying rotor supporting an absorbent creates an atmosphere in which moisture and chemical contaminants are eliminated. With an even higher performance air filter, particles in this air can be eliminated and fed to a dry room. A clean, dry environment with a dew point of –60°C (equivalent to a moisture content of less than a thousandth of that of a general atmosphere) in the case that the dehumidifying rotor is configured as a one-stage system or a dew point of –100°C (less than one millionth) in the case that it is configured as a three-stage system can be created.

The same figure shows the dew-point temperature and the organic-chemical-contaminant removal efficiency in a dry room using a dehumidifier with a three-stage rotor. Immediately after an air filter (which has been stored under a general atmosphere) was attached, the dew point dropped to –70°C, and after about one day it reached the –100°C level. Moreover, in regards to this low-dew-point system, organic-matter elimination of over 99% can be achieved simultaneously(1),(6).

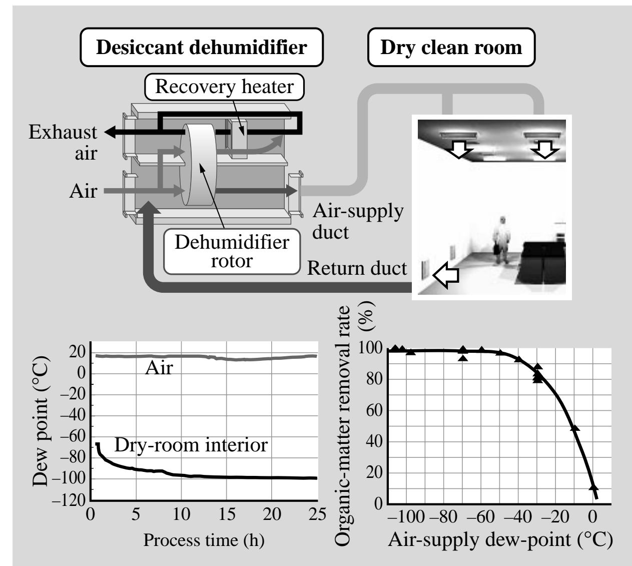

Fig. 5—Low-dew-point Environment System.
An energy-saving low-dew-point-environment system using a dry dehumidification method was developed. Clean, dry air can be supplied at a dew-point level of –60°C by one step of a dehumidifying rotor or at –100°C in three steps.

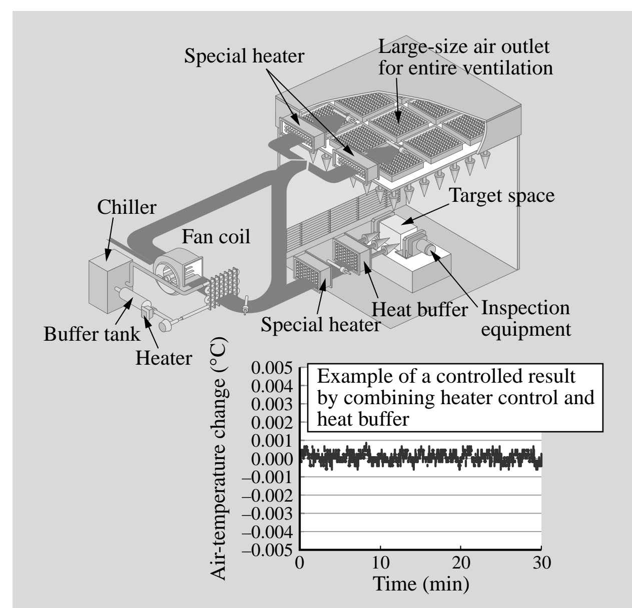

Fig. 6—High-precision Temperature-control System.
A constant-temperature chamber that can control air temperature fluctuation in 0.001°C was realized.

High-precision Temperature-control System

An overview of a high-precision temperature-control system suitable for an environmental chamber for inspection of semiconductor component is shown schematically in Fig. 6. The configuration of this system combines a fan coil unit (with chilled water produced by a chiller) as a heat source and temperature control by a heater. Its distinguishing characteristic is suppression of temperature variation by combining (1) advanced control of temperature variation of heat-source chilled water by means of a buffer tank, (2) air-temperature-variation control by a newly developed specialized heater with high responsivity to periodic temperature variations in the range of several tens of

seconds, and (3) control of even-shorter-period air-temperature variation with a heat buffer. Integrating these technologies has made it possible to suppress variation in air temperature at the ventilation air-supply opening to less than ±0.001°C (within 10 min)(7).

CONCLUSIONS

This paper described development examples of ballroom-type clean-room systems and local precision-environment systems as clean-room technologies for the era of mini-environment systems. As regards processes to fabricate miniature, high-performance devices, in addition to fabrication and inspection equipment, clean-room technologies for establishing the fabrication environment are indispensable. Furthermore, while cost reduction and energy saving continue to advance, it is vital to efficiently control the local environment directly surrounding manufactured products in order to provide a cleaner and more precise environment.

From now onwards, aiming to enhance the technologies described in this paper in accordance with the needs of environments for fabricating various products like semiconductors, FPDs, and HDDs, Hitachi Group will continue contributing to cutting-edge fabrication technology as "total clean technology" for supporting improvements in efficiency, quality, and product yield (see Fig. 7).

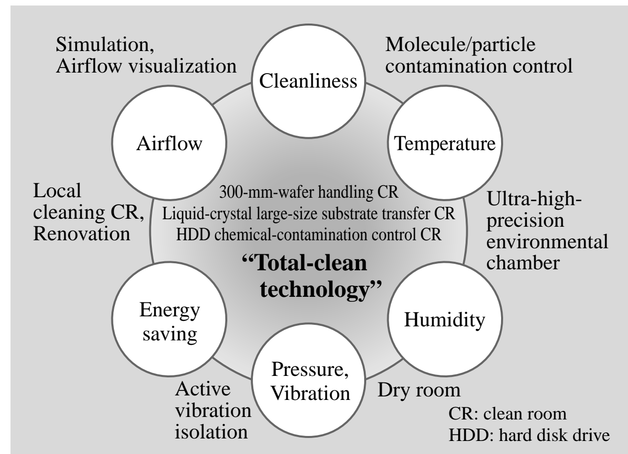

Fig. 7—"Total Clean Technology."
For high-yield, high-efficiency, high-quality fabrication of semiconductors, FPDs, HDDs, and so on, clean-room integrated technology is provided.

REFERENCES

(1) T. Kure et al., "High-cleanliness Technology for Inside Mini-environments," *Electronic Parts and Materials*, Kogyo Chosakai Publishing, Inc., pp. 37–41 (August 2006).
(2) "Clean Rooms of Hitachi Plant Technologies, Ltd.," *Electronic Journal* (2007 Semiconductor Fab/Equipment/ Facilities), pp. 120–123 (September 2006).
(3) ITRS 2005 Edition (December 2005).
(4) "300-mm-wafer Processing of Renesas Technology Corporation," *Electronic Journal* (2007 Semiconductor Fab/ Equipment/Facilities), pp. 102–104 (September 2006).
(5) Y. Kashirajima et al., "Evaluation of Air Quality inside Equipment Front End Module," Proceedings of the 23rd Annual Tech. Meeting on Air Cleaning and Contamination Control, pp. 37–39 (April 2005).
(6) N. Awazu et al., "Study on Removal Performance of the Organic Compounds by Desiccant Dehumidifier," Proceedings of the 24th Annual Tech. Meeting on Air Cleaning and Contamination Control", pp. 222–224 (April 2006).
(7) M. Tanaka et al., "Research on a Precision-temperature Control Chamber (second report), Investigation on a Combination of a High-responsivity Heater and Heat Buffer," collected papers for conference lecture of the Society of Heating, Air-Conditioning and Sanitary Engineers of Japan, pp. 405–408 (August 2005).

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