

Development of High-Speed High-Precision Cooling Plate

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As the thinning of semiconductor device progresses more remarkably than before, temperature uniformity within silicon wafer comes to be strongly required on the cooling plate that is used in the coater/developer system for semiconductor fabrication. Besides, to improve productivity, high-speed cooling and the upsizing of cooling plate are also required. However, it has been believed impossible to meet these requirements at the same time with conventional cooling plate.

Under such circumstances, Komatsu succeeded in developing world-largest-area thermoelectric module for the cooling plate, through using Komatsu's excellent thermoelectric-element technology, as well as achieving high performance to meet the strict requirements. This report describes our development study. The technologies introduced in this report were transferred to Komatsu Electronics, Inc. for putting to practical use.

Key Words: Cooling Plate, Thermoelectric Module, Coater/Developer, Silicon Wafer, High-Speed Cooling

1. Introduction

As the thinning of semiconductor device progresses more remarkably than before, the coater/developer system that is adapted to chemically amplified resist will be dominant in the future, and high-performance comes to be strongly required on the cooling plate used in coater/developer system.

Advance investigation revealed that performance improvement would be limited if achieved only by improving conventional cooling plate and that it would be impossible to manufacture high-performance cooling plate that is adaptable to thinning and high-speed.

Therefore, Komatsu developed world-largest-area thermoelectric module for cooling plate, through using Komatsu's excellent thermoelectric-element technology, and succeeded in achieving high performance and meeting the strict requirements.

This report describes the developed new cooling plate featured by high-speed cooling, uniform temperature within wafer, and large size.

2. What Is Cooling Plate?

Cooling plate is an important component of the coater/developer system that coats, bakes and exposes photosensitive material on silicon wafer to generate a pattern. Silicon wafer is repeatedly heated and cooled in the coater/developer system, where cooling plate is used in the cooling process. Recently, as the thinning of semiconductor device progresses more remarkably than before, it comes to be required to coat photosensitive material thinner and more uniformly. For this, it is necessary to accurately control the temperature of silicon wafer. Cooling plate needs to rapidly cool the heated high-temperature silicon wafer and at the same time control such that temperature within silicon wafer becomes uniform.

Fig. 1 shows the schematic diagram for the semiconductor fabrication process using cooling plate.

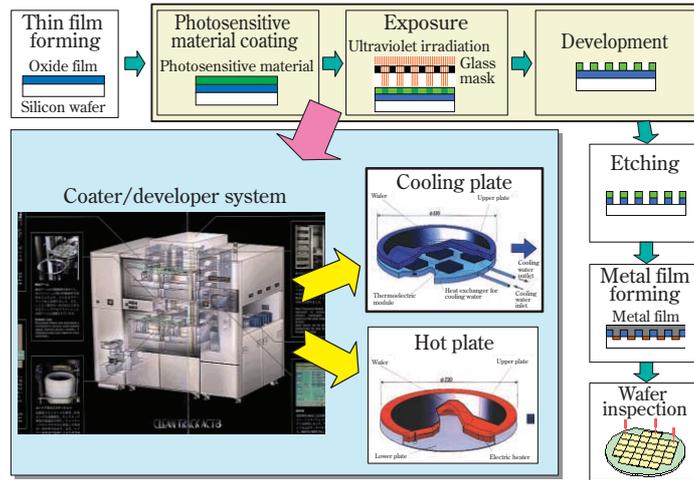


Fig. 1 Semiconductor fabrication process and cooling plate

Fig. 2 shows the structure of conventional cooling plate. It consists of an aluminum plate to put a wafer on, a general-purpose thermoelectric module, and a water-cooled heat exchanger for releasing the heat developed by the thermoelectric module. Fig. 3 shows a photo of the inner structure with the upper aluminum plate removed.

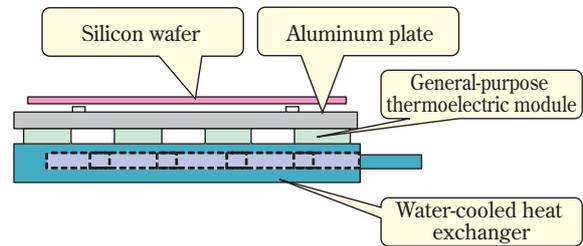


Fig. 2 Structure of conventional cooling plate

For the operation of cooling plate, when a heated wafer is put on the aluminum plate, the temperature sensor buried in the plate detects the wafer to activate the thermoelectric module. The heat absorbing effect of the thermoelectric module cools the aluminum plate, which results in cooling the wafer. The heat radiation from the bottom of the thermoelectric module is removed by the water-cooled heat exchanger.

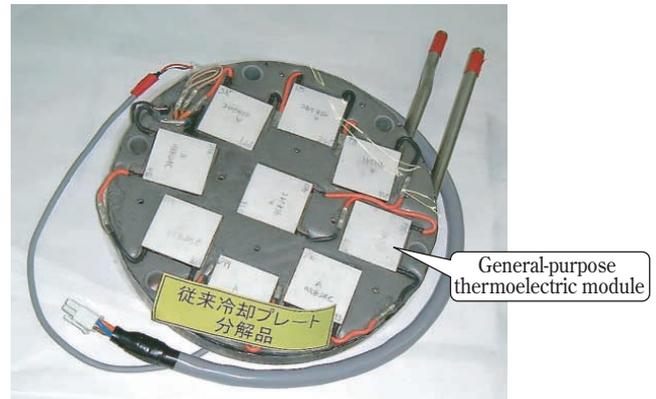


Fig. 3 Structure of conventional cooling plate (photo)

- The required performance of cooling plate is as follows:
- (1) In order to achieve high throughput, high-speed cooling of high-temperature wafer to target temperature
 - (2) In order to adapt to thinning process, uniform control of temperature within wafer
 - (3) Adaptation to $\phi 300$ mm wafer process (conventional wafer size: $\phi 200$ mm)

3. Subjects of Conventional Cooling Plate and New Cooling Plate

3.1 Subjects of conventional cooling plate

Subjects of conventional cooling plate are:

- (1) High-speed cooling results in worsened temperature distribution within wafer.
- (2) It takes a long time for the temperature distribution within wafer to converge.
- (3) Not adapted to large size wafer

For example, if the current value of the thermoelectric module is increased to increase cooling speed, a temperature distribution that follows the shape of the thermoelectric module is generated, resulting in increased temperature difference within wafer. To obtain a uniform temperature distribution in spite of such temperature difference, it is inevitable to reduce the cooling speed. In addition, even when the thickness of upper aluminum plate is reduced to improve heat transmission and thus increase cooling speed, improper temperature distribution will be resulted.

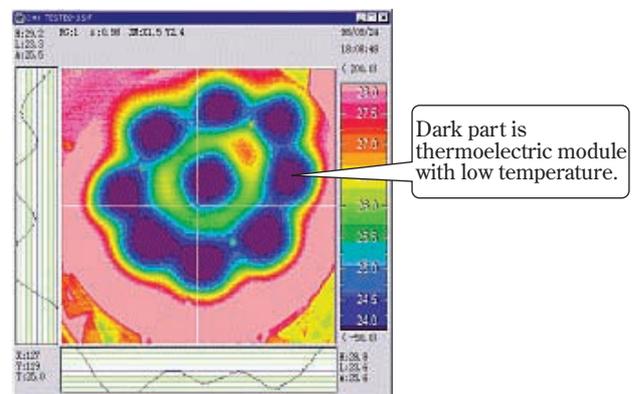


Fig. 4 Temperature distribution of conventional cooling plate (infrared thermography)

Fig. 4 shows the surface temperature distribution of the aluminum plate measured with an infrared thermometer.

3.2 New cooling plate

3.2.1 Specifications for the new cooling plate

Table 1 shows the specifications for the new cooling plate.

Table 1 Specifications for new cooling plate

Item	Specification
Surface temperature distribution within wafer	Set temperature $\pm 0.1^{\circ}\text{C}$ 1/3 the conventional value
Wafer cooling speed	Twice the conventional value

3.2.2 Structure and appearance of new cooling plate

Fig. 5 is the photo showing the appearance of the new cooling plate; Fig. 6 shows its cross-sectional structure.

Outside dimension is $\phi 340$ mm, and the plate surface to put a wafer on is machined to high flatness of $30\mu\text{m}$ or less.

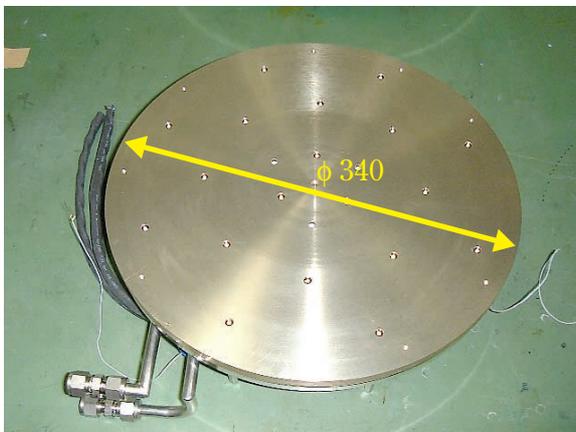


Fig. 5 Appearance of new cooling plate

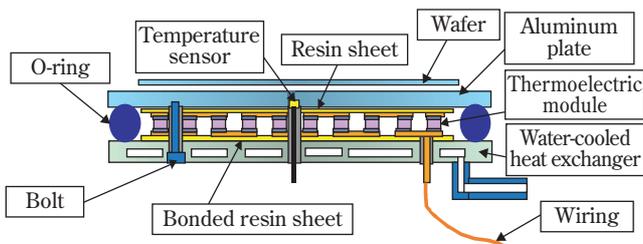


Fig. 6 Cross-sectional structure of new cooling plate

3.3 New technologies

Because it is impossible to meet the requirements with conventional structure, we developed the following new technologies and devices:

- (1) Integration of large-area thermoelectric module and water-cooled heat exchanger
 - (2) High-precision control of large-area module by zoning
 - (3) Other manufacturing technologies
 - ① High-flatness machining technology (plate upper and lower surfaces, electrode surface, etc.)
 - ② Electrode manufacturing and bonding technologies
 - (4) Development of new control method
- Individual technology is described in detail below.

3.3.1 Large-area thermoelectric module

With conventional cooling plate, general-purpose thermoelectric module and water-cooled heat exchanger are separate parts. For the new cooling plate, thermoelectric module and water-cooled heat exchanger are made to be the same in size and integrated into one body. This makes it possible to cool wafer over its entire surface, solving the conventional problem of non-uniform temperature distribution between the portion where general-purpose thermoelectric module exists and the portion where no general-purpose thermoelectric module exists. Besides, cooling capacity is improved by increasing the cooling area and densely arranging thermo-elements.

Fig. 7 is a photo of the large-area thermoelectric module for the new cooling plate. Module size is $\phi 325$ mm in diameter, and approximately 1200 pairs of new thermo-elements are used.

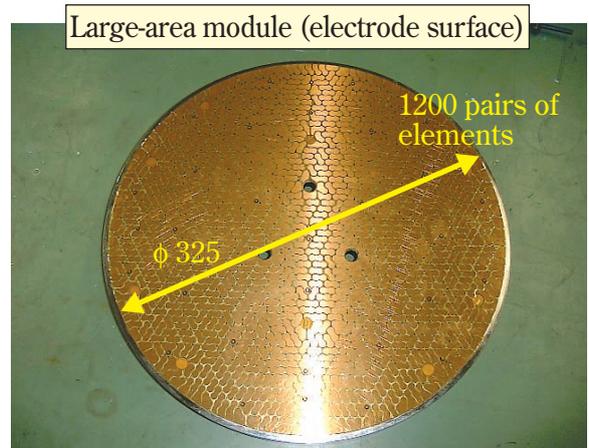


Fig. 7 Thermoelectric module of new cooling plate (photo)

Because this module was newly developed this time, it is necessary to sufficiently investigate its durability. While conventionally used general-purpose module has the structure that upper and lower surfaces are fixed to ceramic substrate, this module has half skeleton structure.

Fig. 8 shows the comparison of structure between general-purpose module and large-area module. Though the lower surface electrode of large-area module is fixed to the water-cooled heat exchanger, because the upper surface electrode is not fixed, the stress resulted from thermal expansion due to the temperature difference between upper and lower surfaces can be released.

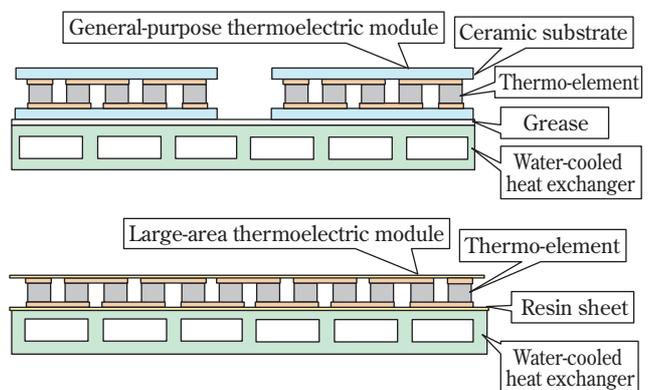


Fig. 8 Comparison of module structure

To investigate the durability of half skeleton structure, we performed thermal stress analysis. For comparison, general-purpose thermoelectric module (the electrodes of which are fixed to ceramic substrate) were also analyzed, the result of which is shown in Fig. 9. Compared with general-purpose thermoelectric module, stress is reduced to approximately 1/3, so that the improvement of durability can be expected.

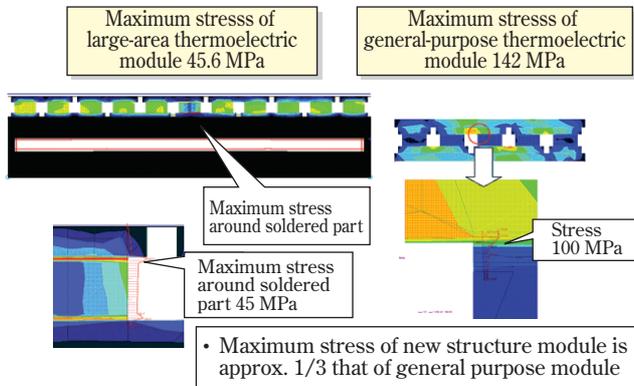


Fig. 9 Comparison of the result of thermal stress analysis

Durability confirmation test was executed, where a temperature difference greater than that of actual operation was introduced between the upper and lower surfaces of thermoelectric module, and the polarity of the current applied to thermoelectric module was reversed to reverse the temperature of upper and lower surfaces. This cycle was repeated 1,000,000 or more times. After the test, no increase of electrical resistance was recognized. Thus, we obtained a satisfactory result also concerning durability.

3.3.2 Zoning

When a high-temperature wafer is cooled with an unzoned thermoelectric module, a temperature difference occurs between the inner and outer portions because the peripheral portion of wafer is cooled faster than the inner portion due to greater heat radiation. To eliminate this temperature difference, it was decided to zone the heating area into inner and outer portions. Besides, depending on the direction of wafer transfer, a temperature distribution with gradient occurs on initial wafers. To cancel this temperature distribution, peripheral portion was further zoned into 4 sections.

Optimum zoning was determined based on the result of heat analysis. Fig. 10 shows the result of two cases: zoning into two inner and outer portions and zoning the outer portion further into 4 sections.

In the case of zoning into two inner and outer portions, the temperature difference of 25°C that had existed within wafer when cooling was started became 0.55°C in maximum temperature difference. This means that the influence of initial temperature difference remains. In the case of zoning the outer portion further into 4 sections, the maximum temperature difference was 0.17°C, which means that initial temperature difference can sufficiently be canceled. This heat analysis made it possible to precisely predict temperatures and to reduce the required number of prototypes.

For this analysis, we used general-purpose thermal analysis software, which was improved to include the calculations of thermoelectric performance and temperature control.

3.3.3 Other manufacturing technologies

1) High-flatness machining technology

The clearance between wafer and aluminum plate during cooling is 50µm. If the flatness of individual member is poor, a dispersion of heat transfer occurs, making it impossible to achieve uniform temperature distribution within wafer. To solve this problem, it is necessary to manufacture aluminum plate, electrode and water-cooled heat exchanger with excellent flatness. For example, in order to finish aluminum plate to high flatness, not only advanced cutting technology must be used, but also proper material must be selected. Through trial and error we succeeded in achieving the required flatness by using the annealed aluminum alloy that contains magnesium, etc.

Also for the flatness of the electrode surface of thermoelectric module, we succeeded in meeting the requirement by devising the soldering jigs.

2) Electrode manufacturing and bonding technologies

Module electrode was manufactured by bonding a copper foil on a resin sheet and then etching the copper foil. This makes it possible to manufacture approximately 1200 pieces of positioned electrode as a batch and to eliminate electrode arranging work.

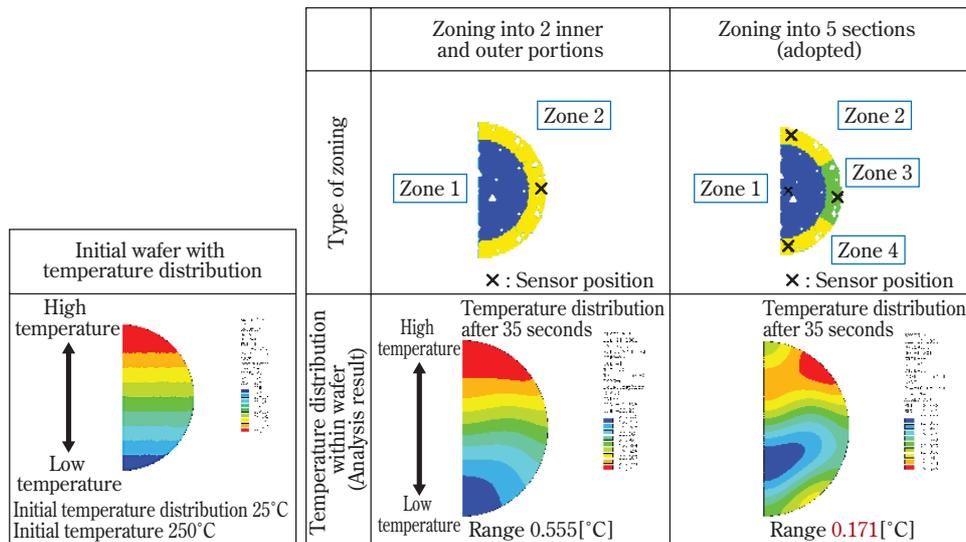


Fig. 10 Zoning and temperature distribution analysis

3.3.4 Control

Conventionally cooling plates have been PID controlled which requires a long time for temperature to converge and is easily influenced by disturbance. Therefore, we made an improvement and developed a new control system, which consists of the following.

- (1) Paddy approximation of dead time
- (2) Configuration of type 1 servo system (3rd order)
- (3) SMC (sliding mode) design
- (4) Combination with disturbance observer (3rd order) having the Paddy approximation error compensation function

Fig. 11 shows the comparison of result between conventional control and newly developed control. Compared with conventional method, the time required for temperature to converge was reduced to approximately 1/6.

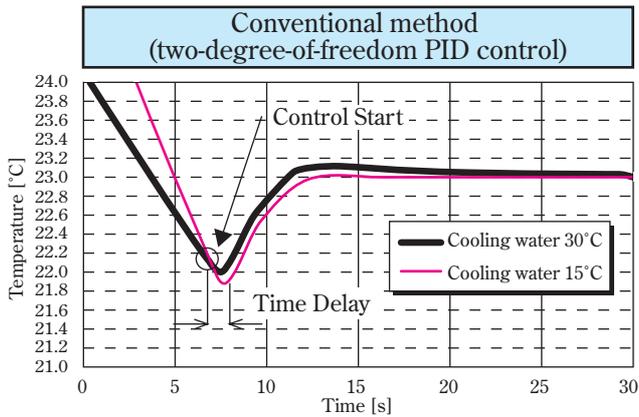


Fig. 11 Comparison of conventional and new control methods

3.4 Performance

For performance check, a wafer sensor for measurement that was heated to 250°C was put on the cooling plate, and the time required for the indication of all the temperature sensors buried in the wafer to converge within 23°C±0.1°C was measured. This was repeated till similar temperature trajectory was obtained, which is regarded as confirmed performance.

Fig. 12 is the photo when temperature was measured.

Fig. 13 shows an example of confirmed performance. In spite of high-speed cooling, no hunting was recognized, and temperature distribution converged in a short time. Fig. 14 shows an example of confirmed performance with continuous processing. Similar temperature trajectory was obtained consecutively.

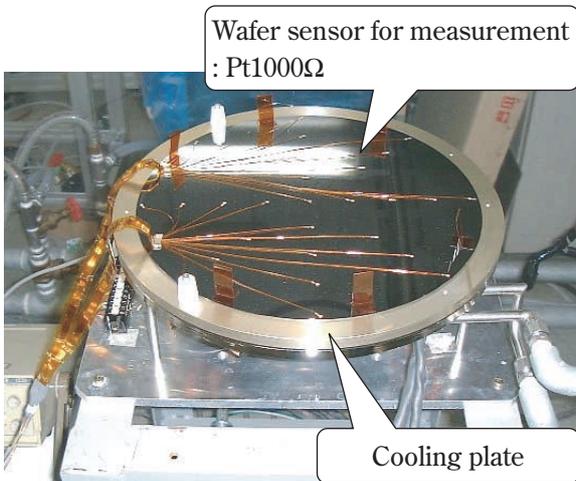
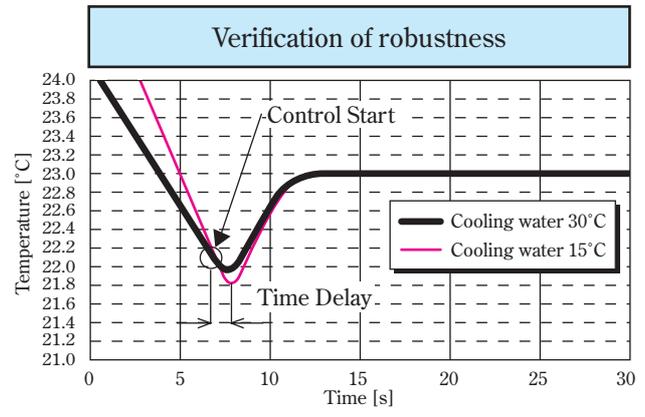


Fig. 12 Performance measurement

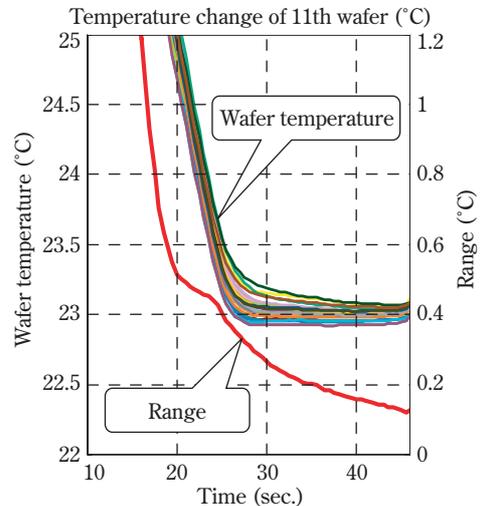


Fig. 13 Confirmed performance

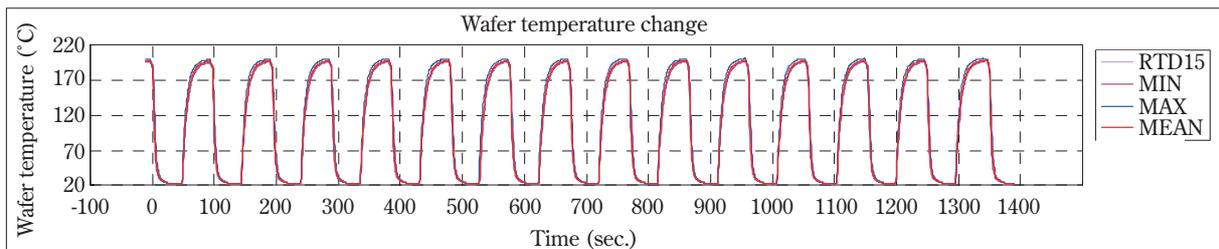


Fig. 14 Confirmed performance with continuous processing (Wafer temperature: 200°C → 23°C)
 ※ Wafer temperature trajectory for odd-number (1st, 3rd, 5th, 7th ...) cycles

4. Conclusion

High-speed, high-precision cooling plate for coater/developer system was developed, and the following result was obtained.

- (1) High-speed cooling of $\phi 300$ mm wafer became possible.
- (2) It became possible to make small the temperature distribution within wafer.
- (3) It became possible to manufacture large-area thermoelectric module.
- (4) Heat transfer analysis became possible that combines thermoelectric performance and temperature control.
- (5) High-speed, high-precision temperature control became possible, utilizing the new control method.

New technologies as the fruit of this study were transferred to Komatsu Electronics, Inc. in the autumn of 2001, and sample shipment was started in 2002 and mass production in 2003.

Introduction of the writers



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[A few words from the writers]

We remember two things about the development of this time. One is that our proposal of developing a large-area thermoelectric module was not recognized at all and, instead, we were advised to abandon such idea because the module would soon be damaged. Remembering it now, we believe that if we had stopped the study, there would be no success. The other is the prototyping of large-area module ($\phi 200$ mm). It was manufactured entirely by hand and required considerable time. The module, however, was damaged when we finally finished it and turned the power on. We were very miserable.

We will continue research and development also in the future to contribute to KOMATSU's providing good products.