Development of Thermal Processing Tool for Minimal Fab

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Minimal Fab is a new semiconductor manufacturing system that is specialized for small lot production, advocated by the National Institute of Advanced Industrial Science and Technology (AIST). The project has been proceeding so smoothly that developers have demonstrated the manufacture of transistors at an exhibition venue[1]. Koyo Thermo Systems currently participates in the project and is in charge of the thermal processing tool. In this report, we introduce the details of the development of the tool.

Key Words: *Minimal Fab, semiconductor manufacturing equipment, resistance furnace, energy saving*

1. Introduction

Minimal Fab is a new semiconductor manufacturing system developed with the aim of drastically lowering investments for semiconductor device manufacturing. At large-scale factories that conduct bulk manufacture of semiconductor devices (hereafter referred to as "Mega Fab"), a group of meters-wide processing equipment is installed which process silicon wafers 300 mm in diameter in each process. Furthermore, to prevent particles from adhering to the wafers, this group of equipment is installed in a clean room. On the other hand, with Minimal Fab, wafers 12.5 mm in diameter are processed one at a time in single wafer processing, with a target of completing each process within one minute. Each unit of processing equipment has been standardized on an body exterior 294 mm in width, 450 mm in depth, and 1 440 mm in height. The areas inside the tool in which the wafer is exposed have been made clean locally, and wafer transport between tools is conducted using a sealed carrier named minimal shuttle, eliminating the need for a clean room. As a result, in comparison to 500 billion yen in investments required for a single plant for Mega Fab, Minimal Fab can be installed for only 1/1 000th of this amount, which is 500 million yen. In addition, maintenance expenses can be kept down since a clean room is not necessary, as well as for other reasons[2].

The target of Minimal Fab is the multi-variety, low-volume market. In terms of monetary value, the multi-variety, low-volume market constitutes approximately half of the semiconductor market, amounting to a market scale of 10 trillion yen. Minimal Fab is suited for multi-variety, low-volume production, and in the case of the production of 10 000 Large-Scale Integrated (LSI) circuits, reduces the cost per chip area by 1/8th that of Mega Fab, and can shorten the one- to six-month delivery time of Mega Fab down to a mere one to three days[3].

Minimal Fab development is sponsored by the National Institute of Advanced Industrial Science and Technology (hereafter referred to as "AIST"), and conducted by a consortium (Fab System Research Consortium) comprised of approximately 130 organizations and companies (as of April 2016). To promote process and equipment development in particular, the Minimal Fab Development Association was established by the AIST and 23 private companies (as of April 2016). Tools are developed by the specialized companies. We Koyo Thermo Systems were responsible for the development of a resistance heating type thermal processing tool, achieving a minimal resistance furnace able to thermal-process wafers in an atmosphere of nitrogen or oxygen at atmospheric pressure.

The following passages of **Chapter 2** will discuss the outline of the minimal resistance furnace and explain the application of thermal oxidation to silicon wafers. **Chapter 3** will discuss applications to other processes based on the resistance furnace.

2. Minimal resistance furnace

2. 1 Equipment overview

The appearance of the minimal resistance furnace is shown in **Fig. 1**. The shuttle is set on the docking port beneath the touch screen, and when the start button is pressed, the wafer is removed automatically from the minimal shuttle and transported to the process chamber. After processing, the wafer is returned automatically to the minimal shuttle. Then, the minimal shuttle is set on another tool for the next process. The processes progress by repeating this sequence of actions.

The body frame, cover, touch screen, and internal wafer transfer unit of the Minimal Fab equipment are standardized, allowing each company to devote themselves solely to the development of the processing sections.

Fig. 1 Schematic view of the minimal resistance furnace

2. 2 Minimalization of furnace

Figure 2 shows the structure of the thermal processing unit of the minimal resistance furnace. The fundamental structure is based on our vertical furnace for semiconductor thermal processing. We set the maximum power consumption of the heater which acts as the heating source to 700 W of the 1 kVA designated power capacity of Minimal Fab equipment, and designed the heat system so that the power consumption of the heater, regarding the maximum operating temperature of 1 200 ℃, is less than half the maximum power of the entire tool4). The heat radiating from the heater is expelled by a fan on the ceiling of the equipment exterior, and although the heater surface and surface of the equipment exterior are at minimum only 5 cm apart, the surface temperature of the equipment exterior which the operator can touch is suppressed to around 40 ℃.

The wafer boat moves upwards and downwards via the elevator, and for thermal processing, the wafer is received from the wafer transfer unit into the transport chamber beneath the heater and then loaded into the process tube. Like the conventional furnace, temperature is controlled by a thermocouple for external temperature (TC: Thermocouple) and a TC for internal temperature in a cascade control arrangement, and this structure suppresses the effects of outside disturbance. Space-saving is also achieved by the placement of the TC for internal temperature inside the wafer boat. The internal volume of the process tube is only 50 cm^3 when the wafer boat is loaded, and therefore the amount of oxygen gas used for dry oxidation process has been reduced to 20 cm^3/min. The tool contains a 1 L oxygen gas cylinder with a charging pressure of 9.8 MPa, allowing 72 hours of dry oxidation process per cylinder.

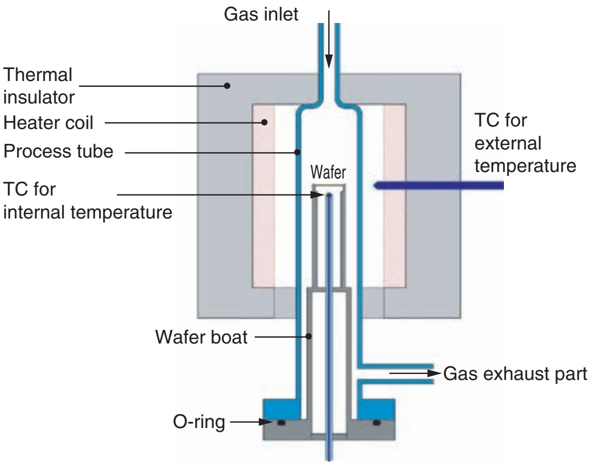

Fig. 2 Cross section view of thermal processing unit

2. 3 Reduction of process time

A resistance furnace heats the wafer indirectly by heating the surrounding atmosphere, and therefore the time required for thermal processing is the same regardless of the amount of wafers loaded into the process tube. Consequently, Mega Fab equipment performs batch processing of several tens of wafers. However, the minimal resistance furnace conducts single wafer processing, which creates a bottleneck within semiconductor manufacturing processes. For this, a reduction in process time is necessary.

There are two approaches to reduce process time. One is to reduce the time of actual thermal processing, for which methods such as changing the process gas (from oxygen to steam) or the high pressurization of the process gas within the thermal oxidation process are considered. The second is the reduction of time other than thermal processing time. The second approach shall be explained in this section.

In semiconductor thermal processing equipment, in addition to the placement and removal of wafers on the boat and the loading and unloading of the boat into and from the process tube, it is necessary to raise the temperature of the heater to the processing temperature from that when the wafer is loaded, and lower the temperature after processing when the wafer is unloaded, since in case of high temperature processing the temperature must be lower than the processing temperature when loading and unloading the boat. These steps require time other than that for the actual thermal processing. The reason for the raising and lowering of the temperature is that since the heat capacities of the wafer and boat are large, and the area and thickness of the wafer is large, it is necessary to raise and lower the temperature while minimizing temperature distribution within the wafer to avoid crystal defects within the wafer.

In the minimal resistance furnace, loading and unloading of the boat into and from the process tube can be conducted rapidly since the heat capacities of the boat and wafer are small. It is also possible to load and unload the boat directly into the heater at the processing temperature for high-temperature processing, eliminating the necessity of raising and lowering the temperature as for the conventional equipment. As shown in **Fig. 3**, time required for that other than thermal processing within the minimal resistance furnace is 10 minutes, the order of which is 1/10th that of conventional equipment.

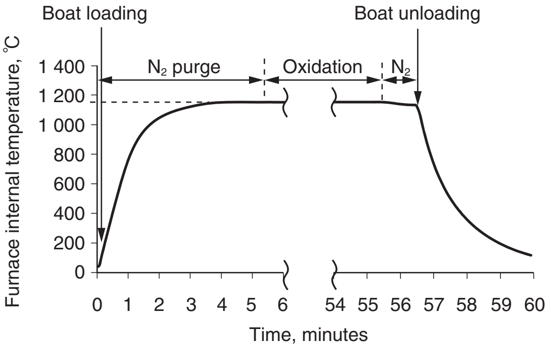

Fig. 3 Example of temperature profile in thermal oxidation process

2 .4 Evaluation of the resistance furnace

Within a group of Minimal Fab tools, it is particularly important to ensure localized cleanliness for the minimal resistance furnace. This is because the process is implemented at a high temperature of over 1 000 ℃ for the thermal oxidation process, and therefore if impurities adhere to the wafer, these impurities will quickly diffuse within the wafers due to the high temperature, which will impair the function of the semiconductor device in the end. Therefore, in order to evaluate whether the tool has sufficient cleanliness, Ikeda et al. of AIST fabricated an MOS (Metal-Oxide Semiconductor) capacitor using a silicon wafer that was thermally oxidized in that tool and conducted an evaluation of the capacitor's electrical properties.

Detailed results of this evaluation are shown in a reference5). From the gate voltage dependency of the electrical capacity of the MOS capacitor, we found that the fixed charge density of the oxide film was 9.4×10^9 cm^{-2}, and that the interface state density was 1.38×10^{10} cm^{-2} to 1.77×10^{10} cm^{-2}, which are both levels indicating no problems within the manufacture of semiconductor devices.

3. Development

As the next step, we are currently developing a minimal LP-CVD (Low Pressure Chemical Vapor Deposition) furnace based on the developed resistance furnace introduced in the previous chapter. This tool is for the purpose of forming a polycrystalline silicon film and silicon nitride film on the silicon wafer. We have successfully included a complex source gas supply and exhaust system, a vacuum pump, a detoxifying cartridge, and a gas leak detector within the prototype tool, which conforms to the Minimal Fab concept.

We are currently using this prototype to conduct an evaluation of the polycrystalline silicon film formation process while evaluating the operations of the mounted parts. Although monosilane is usually utilized for polycrystalline silicon film formation, we are investigating the usage of dichlorosilane for the film formation process within Minimal Fab. As dichlorosilane is liquid at room temperature, this is to enable the downsizing of the source gas container within the tool body, and is also to avoid using special high-pressure gas.

Furthermore, we are working to develop a minimal pyrogenic oxidation furnace and a minimal high-pressure oxidation furnace in order to reduce process time within the thermal oxidation process.

There are also issues which must be overcome within the development of the minimal tools. First, with the downsizing from the conventional equipment, there are some element parts which have not been sufficiently downsized among the current lineup, and this has worsened the maintainability of equipment which contains many parts, such as the LP-CVD furnace. Therefore, we are progressing with development of the parts downsizing with the cooperation from parts suppliers. Other than this is the issue to develop processes which have never before been implemented within conventional semiconductor manufacturing, such as the aforementioned utilization of dichlorosilane. It is also necessary to evaluate the robustness and stability over time of the tools and processes, maintenance cycle and maintenance methods, proceed with process development and evaluation on production lines for demonstration, looking ahead to operations at semiconductor fabrication plants.

4. Conclusion

We have developed a minimal resistance furnace to conduct thermal processing at atmospheric pressure within Minimal Fab. This furnace achieves energy saving with a heater power consumption that reaches a maximum of 500 W, and with an operating oxygen gas flow rate of 20 cm^3 per minutes. The electrical properties of an MOS capacitor manufactured using this tool are at a level that indicates no problems within the manufacture of semiconductor devices, which shows the achievement of localized cleanliness. In addition, we are currently developing a minimal LP-CVD furnace, based on the minimal resistance furnace, for forming a polycrystalline silicon film and silicon nitride film.

Minimal Fab is an endeavor that proposes a new orientation within the semiconductor industry. It is at a level where a manufacturing line can be launched at an exhibition in half a day and produce transistors, and the feasibility of its application has been clearly recognized within the market as well. Establishment of foundries utilizing minimal equipment has already begun, and it may be said that Minimal Fab has begun racing towards actual application within industry. We Koyo Thermo Systems will continue our efforts to achieve a new *monozukuri* of Japan through this project.

We would like to use this opportunity to once again thank AIST, the Minimal Fab Development Association, and the Fab System Research Consortium, whose joint efforts lead this endeavor.

* MINIMAL is the registered trademark of the National Institute of Advanced Industrial Science and Technology.

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