Advanced Process Control for Semiconductor Thermal Process

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OVERVIEW: In the semiconductor manufacturing field, APC (advanced process control) has just started to be used in a portion of semiconductor manufacturing. To accomplish device manufacturing below 100 nm, a stable thermal process is required, such as the one that eliminates wafer-to-wafer, batch-to-batch, and furnace-to-furnace differences. Equipment condition monitoring ability also has been improved; therefore, predictive and preventive maintenances are required. Reducing furnace startup time and manufacturing in small lots at batch type furnaces are necessary to use furnaces more effectively. Hitachi has developed an APC system for the semiconductor thermal process that (1) reduces thickness differences from wafer to wafer and (2) batch to batch; (3) detects abnormal furnace conditions at an early stage; (4) reduces equipment startup time; and (5) reduces process parameter modification time when the number of product wafers is changed.

INTRODUCTION

TO improve yield, semiconductor device manufacturers adjust subtle differences between furnaces and calibrate furnace fluctuation caused by aging. This work used to be performed manually, but recently an MES (manufacturing execution system) manages it automatically. However, because of more advanced and minute semiconductor process technology, the difficulty of adjustment work is increasing. Manufacturers have difficulty handling this problem on their own; therefore the necessity of maintaining and improving the stability of furnace operation has become more urgent. Equipment condition monitoring and processing huge amounts of data quickly are necessary to reduce down time and MTTR (the mean time to repair).

Presently, with the enlargement of wafer diameter up to 300 mm, reducing the amount of NPW (non-product wafer) is required to cut production cost. To achieve this and to carry out direct solutions, such as forming films within users' required tolerances and so as to avoid producing inferior wafers, are most important. In short, yield must be improved. Additionally, manufacturers need to reduce the use of monitor wafers for tuning furnace setup conditions.

Below, we describe an APC technology that is a key to solving those issues.

ADVANCED PROCESS CONTROL SYSTEM FEATURES

Features of an APC system that Hitachi Kokusai Electric Inc. has developed are described below. Fig. 1 shows a schematic of the APC system.

(1) Controlling the fluctuation of wafer thickness

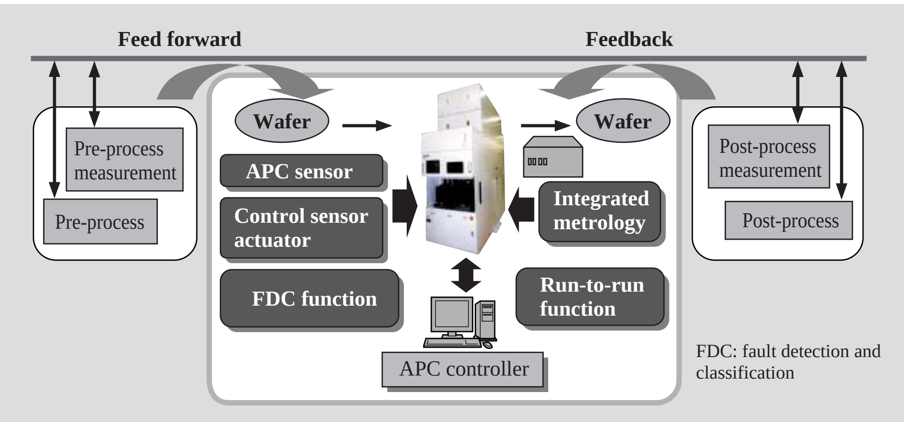

Fig. 1—APC System Schematic.
To achieve better uniformity and stability in film condition, APC controller has been added to semiconductor fabrication equipment. The APC accumulates process and equipment condition information, and optimizes process parameters by using a simulation or mathematical model.

Thickness must be fitted within a range of user's target. Wafer thickness is influenced by conducting a continuous batch process. This APC system achieves this by changing process parameters, such as time or temperature, when a batch process is started. In this case, the system mainly adopts a feedback control mode that uses process results to operate it. However, it can also adopt a feed forward control method that uses previous process conditions.

(2) Equipment error detection and predictive/ preventive maintenance

The APC system monitors equipment condition and detects equipment and process errors. Furthermore, it predicts maintenance work that will be required by processing error occurrence data. The system displays detected errors or informs MES of them and also reports them to maintenance personnel and/or the vendor by e-mail. After an abnormal condition is detected, process execution is stopped to minimize the amount of inferior lots. APC sensors, control sensors, and actuators are needed to monitor the condition of the furnace.

(3) Reduction of fill dummy wafers

This APC system makes possible a batch process without using fill dummy wafers even if the number of process wafers is reduced. Usually when the process mentioned above is conducted, the desired result can not be acquired. However, our system makes possible adopting a system without fill dummy wafers to modify a process parameter and achieves the expected thickness.

(4) Immediate verification of process result

We install an integrated metrology into the equipment, such as a thickness monitor, to verify the result of a process (ex. thickness, particle) and judge whether it is successful.

APPLICATION TO AVOID THICKNESS FLUCTUATION CAUSED BY AGING

Using a furnace many times after maintenance, causes thickness to slightly fluctuate. Especially, for CVD (chemical vapor deposition) furnaces, byproducts are deposited inside of the reaction tube, over the boat, and inside the exhaust pipes resulting in fluctuated film formation. Therefore, process parameters have to be modified manually, but this APC controller controls them automatically, reduces the fluctuation, and resolves the aging issue.

When a batch process is executed, product wafers and monitor wafers dedicated to film quality evaluation are loaded. After the batch process is finished, the thickness metrology tool and particle monitor are used to evaluate the effectiveness of the process and judge the quality of films.

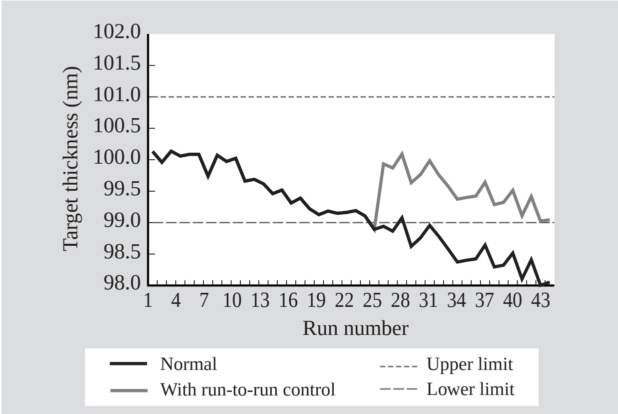

Fig. 2—Results of Adjusting a Process Parameter to Solve Fluctuation Caused by Aging.
Adjusting a process parameter when film thickness exceeds upper or lower limits makes film thickness into the control range.

If the tolerance for film forming is wide, a process parameter need not be adjusted. However, as devices are becoming minute, tolerances are becoming smaller, and this requires process parameter adjustments.

A comparison of an adjusted process parameter and an unadjusted process parameter is shown in Fig. 2.

Following this example, thickness is reduced according to the number of process executions. If any action, such as a process parameter change, is not carried out, an inferior lot will occur. In case a process parameter has to be modified, the APC controller adjusts the process parameter when a certain thickness is reached, as shown in Fig. 2 (100 nm ± 1 nm). In this example, process time is extended to increase thickness. By using this control mode, the thickness is reset to the target thickness range.

APPLICATION TO AVOID THICKNESS FLUCTUATION BETWEEN ZONES

We can load 100 to 150 wafers onto a boat in a batch furnace as usual. At the equipment setup stage, we set process parameters uniformly so that all wafers' condition are almost the same. However, changing external environment and aging gradually increase differences between each wafer. Therefore, we use the APC controller to reduce this fluctuation.

In the vertical furnace, we usually divide the heater unit into five zones and each of these zones can be controlled separately. They are called by Upper (U), Center Upper (CU), Center (C), Center Lower (CL)

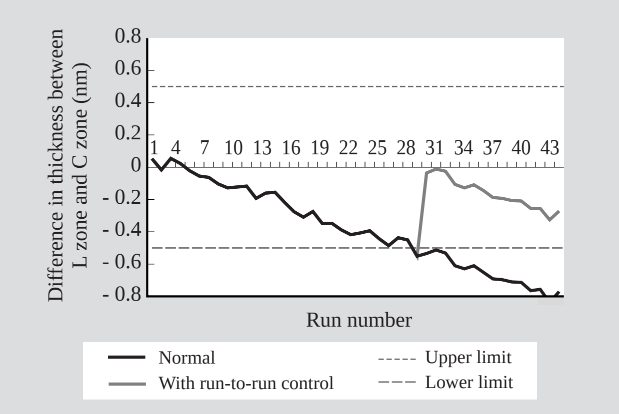

Fig. 3—Control by Using Difference between C-zone and L-zone.
As in the case of fluctuation caused by aging, process parameter is adjusted when the difference of film thickness exceeds lower and upper limit.

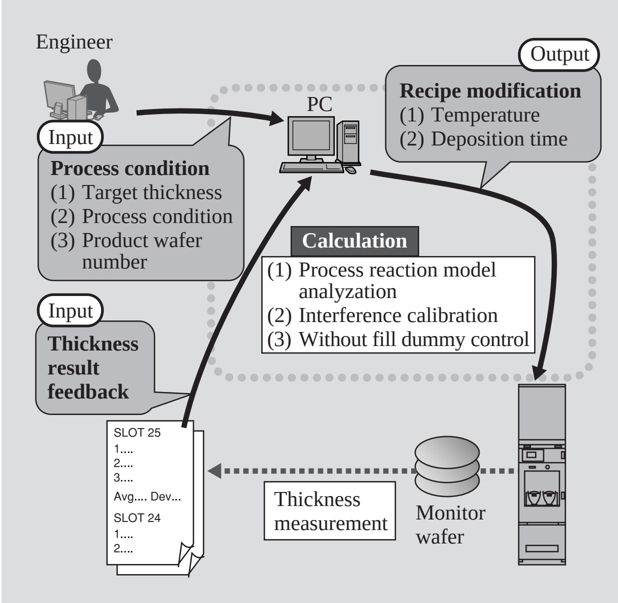

Fig. 4—System Configuration without Fill Dummy Wafers.
Recipe information and thickness data are used to calculate an optimized process parameter for the target number of product wafers.

and Lower (L) from the top. The control method mentioned at the preceding section is used to reduce thickness fluctuation at zone C. The other zones can be controlled individually to reduce thickness fluctuation.

Fig. 3 shows an example of a film thickness difference between C and L zones.

One can use the difference between the C and L zones to change the temperature of L zone when the thickness difference reaches a specified tolerance, in this case it is ±0.5 nm. The example of Fig. 3 assumes that aging causes a fluctuating difference of thickness between C and L zones. Comparing L and C zones, the thickness is less in L zone than in C. When the thickness difference reaches –0.5 nm, the APC controller raises the L zone temperature to restrain a fluctuation of thickness.

Actual temperatures of wafers that are placed in a reactor tube in L zone are lower than in C zone. We assume that the issue above appears in this phenomenon and raising the temperature of the L zone restrains temperature fluctuation between L and C zones. Also, we can apply this control mode to CL, CU and U zones to improve the uniformity of every wafer on a boat.

SYSTEM WITHOUT FILL DUMMY WAFERS

In a batch process, fill dummy wafers are generally used. When a certain number of product wafers is lost, we load fill dummy wafers to maintain the stability of a process condition and always load the same number of wafers on a boat. This is the way to maintain uniformity even if the number of product wafers is changed. In a ϕ200-mm wafer process system, fill dummy wafers are used to take up space not used for product wafers, so not so many fill dummy wafers are required.

A ϕ300-mm wafer process tool will become the main wafer process equipment in the near future, and this system is sometimes required to process a small number of wafers per batch, 25 or 50 wafers, to improve productivity. When using the conventional wafer processing method, we must use many fill dummy wafers to fully load wafers on a boat.

A system without fill dummy wafers is a technique to eliminate the use of fill dummy wafers. If fill dummy wafers are not used, the number of wafers loaded on a boat is changed. Therefore, process conditions have to be changed.

Fig. 4 shows a without fill dummy wafers system.

This system uses input data such as furnace/heater features, process conditions (temperature, gas flow rate, and time), target thickness, in addition to the number of loaded wafers, and adopts a process reaction model (explained below), and an interference calibration formula to calculate recommended process parameters. The process model is a key component of a system without fill dummy wafers.

Commonly, two or three dimensional process models are conducted. Their accuracy is high but a long time is required to calculate because of the large amount of calculation and many parameters.

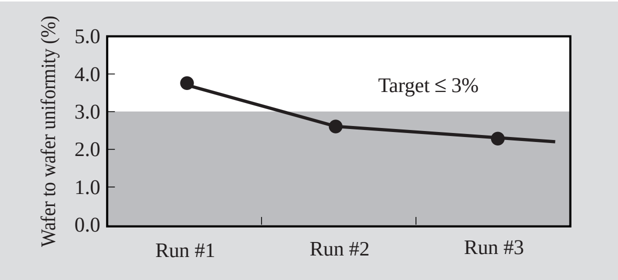

Fig. 5—Wafer to Wafer Uniformity.
Test result of processing 100 of Si_3N_4 wafers using a ϕ200-mm wafers system. By repeating this operation, target wafer to wafer uniformity is achieved.

Therefore, we have developed a one-dimensional process model that enables high-speed calculation to analyze a process. Its accuracy is almost same as the two dimensional process model and its calculation speed is approximately 500 times faster.

Adopting recommended process parameters, which are calculated by this system, enables us to conduct a process with a variable number of product wafers and feedback this result to the system to improve their accuracy.

Fig. 5 shows the result of processing 100 of Si_3N_4 wafers without fill dummy wafers using a ϕ200-mm wafers system with a capacity of 150 wafers.

The result from the first process was a wafer to wafer thickness uniformity of 3.74% and this result was fed back to the system. It improved uniformity to 2.59% at the second run and 2.27% at the third run.

Currently, we are working to improve the analysis accuracy of the process model and to add a database capability for improving thickness uniformity.

INTEGRATED METROLOGY

Generally, devices that measure thickness, particles, sheet resistively and concentration are installed on semiconductor manufacture lines. To complete those measurements takes at least a few hours. If inferior wafers are formed and are not found immediately, the next process will be started in the same furnace and may produce more inferior wafers. Installing metrology tools in a furnace to solve this problem and measuring process results immediately are necessary. We are now focusing on a thickness and particle monitor for a ϕ300-mm furnace.

CONCLUSIONS

We have described an advanced process control technologies that can stabilize the thermal process of wafer fabrication.

As a furnace manufacturer, we continually strive to improve furnace performance, function, and quality by adopting the skills mentioned in this thesis. Our equipment is placed in semiconductor manufacturing lines so we also research and consider the relationship between our furnaces and other tools.

We will endeavor to improve the total functioning of our equipment as a system by developing advanced process control technologies to achieve process stability.

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