High-accuracy Etching System with Active APC Capability

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OVERVIEW: Accompanying the continuing scaling down and increasing precision of semiconductor devices, the requirements regarding the etching process are getting ever more severe. As scaling down with increasing precision and small-lot production of diversified products continue to advance, it is required to consistently set the optimum processing conditions in response to variations in equipment and products. Under these circumstances, along with a ballooning amount of information flowing between shop-floor equipment and the host computer of a semiconductor plant, the burden on process engineers on the device manufacturing side will become even heavier. Focusing on minute variations in processing conditions — which have up till now not caused problems in regards to manufacturing semiconductor devices — Hitachi High-Technologies Corporation has developed an active APC (advanced process control) system for high-precision etching equipment. On top of attaining reproducibility of etching performance in relation to each wafer in a lot as well as between lots, this system can achieve long-term reproducibility, even before and after wet cleaning. High-precision etching equipment fitted with the active APC system is already being operated and evaluated on the production line, thus contributing to stable production of semiconductor devices.

INTRODUCTION

AS regards scaling down of processing to the 90-nm node and beyond, in order to obtain optimum processing results, it is becoming more important to perform fine control by utilizing setting changes in the process recipes for etching equipment, variable parameters, etc. according to inspection and processing information obtained after lithography processing.

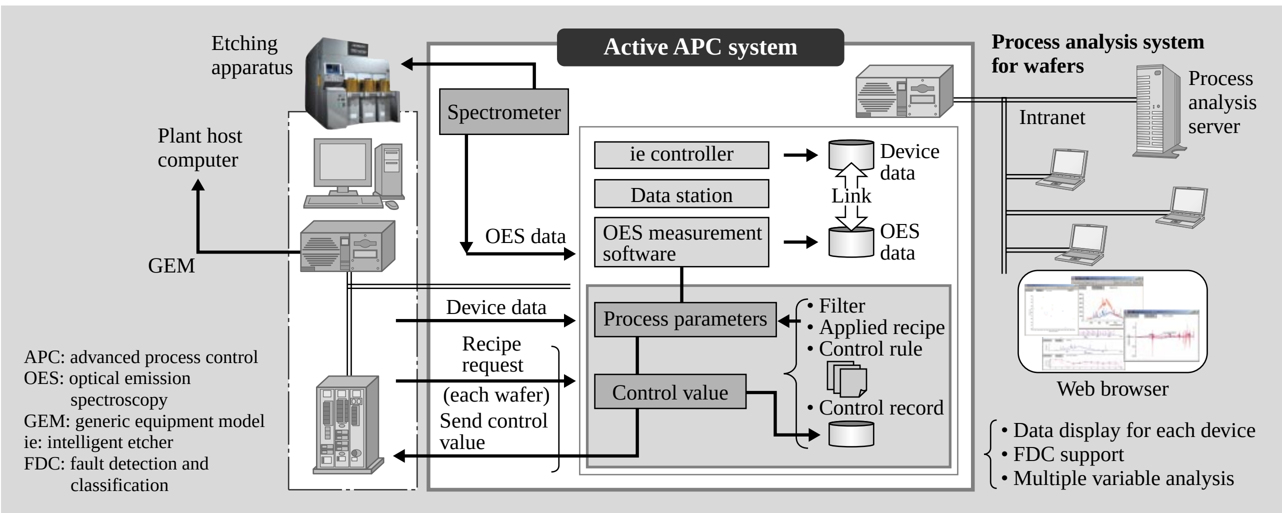

Fig. 1—Overall Composition of High-accuracy Etching System with Active APC Capability.
With this etching system, it is possible to automatically gather etching-device data and OES data, and then, via a network connection to a process analysis server, to analyze various process data on network-connected PCs. Additionally, with this fitted active APC system, it is possible to control the fine detail of the etching patterns on every single wafer.

Aiming at further scaling down of devices beyond the 90-nm node, increasing precision, improving overall equipment effectiveness, and reducing total costs, Hitachi High-Technologies Corporation has developed an “active APC (advanced process control) system” — an etching apparatus with extremely high accuracy that provides excellent reproducibility of etching performance.

This system — designed to handle cutting-edge semiconductor devices — can precisely pick up the changes in processing conditions that until now have not caused problems in conventional devices. That is to say, it enables fine control of every single wafer being processed.

In the following sections of this paper, the characteristics of this system are described, and our expectations for its future applications are outlined.

STRUCTURE AND PROCESS ANALYSIS OF ACTIVE APC SYSTEM

The APC system is composed of a controller, for performing data collection and process control, and an OES (optical emission spectrometer) with add-on sensors (see Fig. 1).

To accomplish high-precision etching, it is necessary to execute fine process control for each wafer. The active APC system gathers together in real-time equipment-status data (e.g. electrical signals from etching apparatuses) obtained from etching-apparatus systems and plasma-OES data obtained from the attached OES spectrometer. It then correlates this gathered data with product information (such as lot information) and manages the correlated data. In the meantime, the data managed in this way is shared with a server kept on-line as a database.

Furthermore, in the case of process-control execution, to enable transfer of control commands and data between the active APC system and the controllers of the etching equipment, etching apparatuses made by Hitachi High-Technologies Corporation are being implemented with appropriate control sequences.

This system can also function as a platform for process analysis. In concrete terms, the active APC system is connected to an intranet, and by adding a supplemental web server to the user’s intranet, each etching apparatus can be hooked up to this server via the network. This means that “data mirroring” of equipment-status data and OES data together with product information can be performed routinely by the web server. As a result of this set up, simply by using PCs and standard web browsers, customers can utilize a process-analysis system that provides a wide variety of graphic displays and analysis functions and enables them to precisely extract the required information from a huge amount of amassed data.

The aim of the process-analysis system is to support the process analysis that becomes most important when active APC is executed. For example, the correlation between changes in the characteristics of a process and the equipment-status data and OES data can be revealed. Since this web-compatible process-analysis system is not merely useful for analyzing individual wafers but also for analyzing trends between lots, plasma-emission spectra, and multivariate analysis, it functions as a complete tool for supporting analysis by users (see Fig. 2).

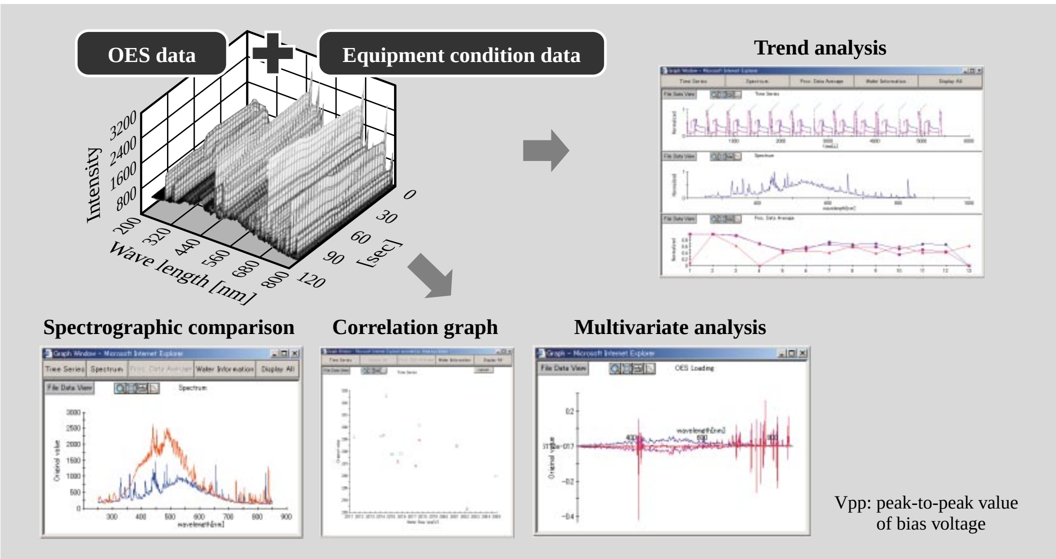

Fig. 2—Main Functions of Web-compatible Process Analysis System.
In the case of the web-compatible process analysis, it is possible to handle not only equipment data but also OES data (which is useful for process analysis) in an integrated manner.

ACTIVE APC EXECUTION PROCEDURE

In the case of dry etching, the balance between ions, radicals, and reaction products in the plasma is a key factor in determining etching feature size (see Fig. 3). For example, if there is an excess amount of reaction products (polymer) in the plasma, a tapered etching profile like that shown on the left of the figure is produced. In contrast, if there is a shortage of reaction products, a notched profile like that shown on the right of the figure is produced. Consequently, if the balance between each of the above-mentioned constituents is monitored, the etching performance can be inferred from the monitoring results.

As a method for monitoring this plasma balance, OES — which obtains spectra from plasma emission — is available. As an example of this spectra monitoring, the following procedure for executing active APC using OES data is outlined below:

(1) Selection of monitoring parameters

To begin with, it is necessary to work out the correlation between process variations regarding the process characteristics in question and OES data. Since OES data is sampled at intervals of less than one second from 2,048 data channels, a huge amount of information is built up. From this information, not only are specific wavelengths extracted but also an etching-reaction model and disturbance causes are supposed, and the information gained from multiple wavelengths is combined. In some cases, this combined information has to be used as process variables.

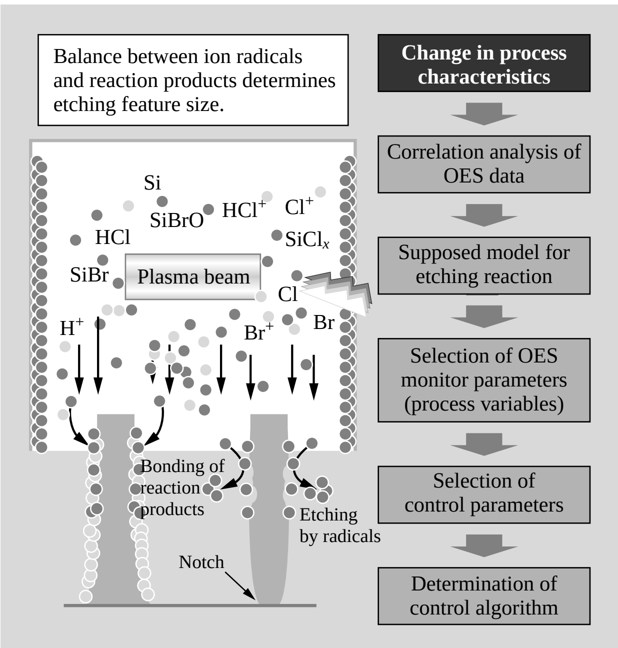

Fig. 3—Etching Reaction Model and Flow for Determining Control Algorithm.
An etching reaction model is assumed according to the OES data obtained during etching, and a control algorithm that obtains high reproducibility is determined.

At this point it must be noted that accompanying the variations in the process characteristics, there are changes in a multiple number of parameters. Among these changing parameters, it is important to identify which parameter is closest to the cause of the change in characteristics.

(2) Extraction of control parameters

Next, it is necessary to determine the control parameters that correspond to the process variables. That is to say, for the obtained process variables described above, which preset values to take as the control target parameters for active APC are determined from among the etching conditions (i.e. gas-flow volume, voltage, etc.). As regards the determined control parameters, it is necessary to validate them experimentally from the viewpoint of controllability and robustness. In this manner, carrying out active APC takes many experimental procedures, which is true for any procedures for putting standard control systems into practice.

(3) Determination of control algorithm

The concept behind the execution of active APC is shown schematically in Fig. 4. In this active APC system, process variables correlated with process-characteristics variations are converged to the specified control target value in such a way that the control parameters are compensated. That is, the difference between the process-variable value obtained from the previous etching results from the applicable etching room and the control target value is used to determine the control value for the next etching.

When executing active APC, care must be taken in the case that the status of the etching apparatus goes outside of the range supposed by the control model. In that case, APC must be executed in such a way so that control does not become abnormal. As for the developed active APC system, upper and lower limits for the process variables together with the control parameters can be set. And when abnormal control of these variables and parameters in relation to the limits is detected, APC operates in such a way to compensate such abnormalities.

Another important point regarding the actual execution of active control is the determination of a control constant called gain offset. If the proper control constants are not set correctly, the control system for active APC becomes unstable and, in the worst case,

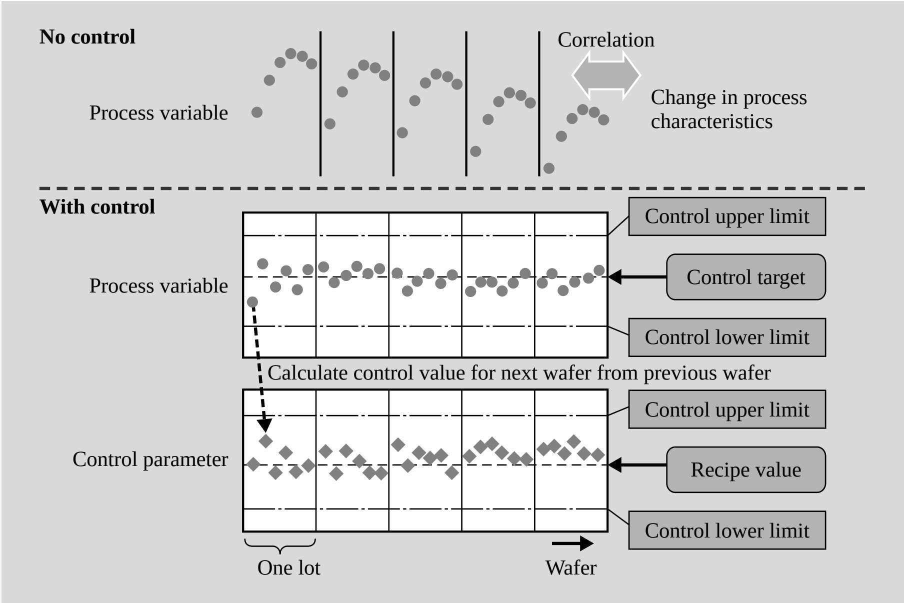

Fig. 4—Execution Concept of Active APC.
In the control method, the deviation between the previous process-monitoring results and the target value is determined, and the conditions for the next etching are set according to that deviation. This procedure is called "run-to-run" control.

nonconformities could be produced in the fabricated wafers. However, investigating control constants while actually executing active control of etching equipment incurs a huge cost and takes time; doing so is therefore not realistic. In response to these issues, we have developed the active APC simulator shown in Fig. 5. In this simulator, variations in previous process variables obtained from process analysis are applied to a control model, and simulation is executed. Applying this simulator enables the optimum control constants to be obtained by simulation before actual active control is executed.

The main consequences of the above-described control system that are applicable to customers' production processes are summarized below.

(1) As a result of stable etching performance, the frequency of equipment maintenance checks can be reduced; consequently, the period between wet-cleaning procedures can be more than doubled.

(2) As a result of regulating equipment conditions, the quantity of NPW (non-product wafer) consumed can be significantly decreased.

As another result of applying the optimized control constants determined by this software simulator, the variation in the process-control results is significantly reduced — i.e. 3 Σ distribution is reduced by about 80%.

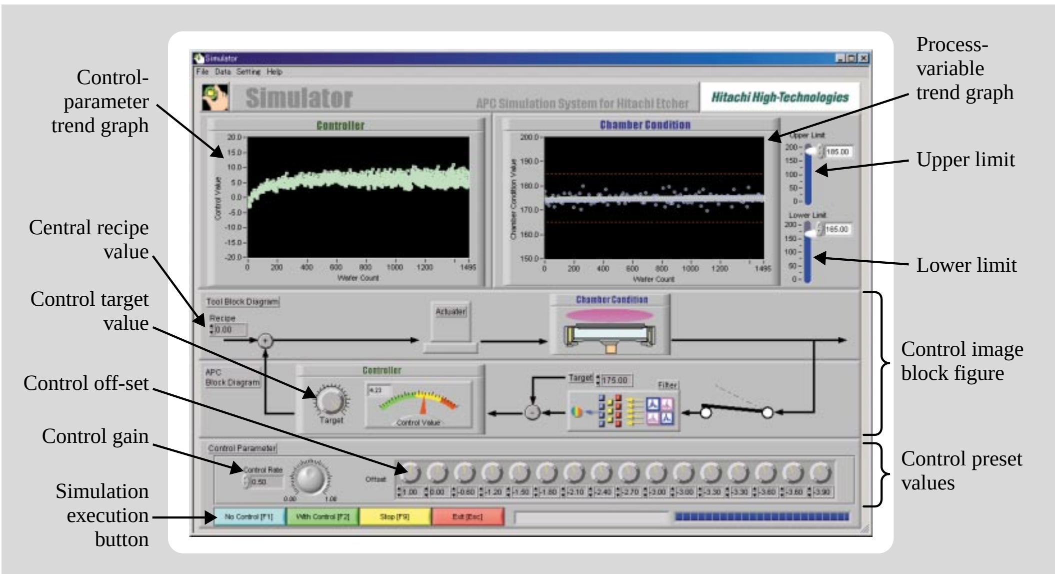

Fig. 5—Active APC Simulation.
Before actual active control is executed, the optimum control constants can be obtained by simulation.

CONCLUSIONS

The fundamental principle, an application example, and the control execution procedure regarding our newly developed active APC system are outlined in this paper.

From now onwards it is expected that the requirements regarding the performance of etching equipment will keep getting tougher and tougher. It is also expected that the same equipment will have to cover a number of different generations of semiconductor devices. Under these circumstances, at the same time as improving the basic performance of etching equipment itself, Hitachi High-Technologies Corporation will further expand the application areas of APC systems while striving to meet the demands of our customers.

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