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Data requirements and communication issues for advanced process control

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Data streams and communication issues are the most critical areas for successful advanced process control (APC) programs. These areas are vital for both APC run-to-run controllers and fault detection and classification (FDC) systems used for high volume manufacturing applications in the semiconductor industry. All APC systems rely on data streams to make their process changes, to keep the process on target and in control, and to otherwise signal a need for engineering involvement to make similar corrective actions. The access to, communication of, and reliability and integrity of these data streams are essential to all APC programs. APC run-to-run controllers use the data to make changes in the process. FDC systems focus on predicting pending equipment- or process- related problems or detecting them quickly when they occur. The inability to access the needed data stream can prohibit the use of APC run-to-run controllers or FDC systems on critical process operations. Worse yet, the use of unreliable or corrupted data can cause undesirable consequences. In order to better capitalize on the improvements demonstrated with APC run-to-run controllers and FDC systems, end users have often had to create their own communication and data processing methods. The first decade of the 21st century will place increased demands on process and metrology equipment manufacturers, APC software and hardware suppliers, and APC programmers. Improvements in these areas through the use of industry standards and best known methods could greatly accelerate the APC field. Wafer-to-wafer and within wafer process control could be essential for 300 mm wafer processing; large flat panel processing will also need these improvements. We will discuss examples that Advanced Micro Devices experienced in Fast atom beam-25 within the past year. The case studies relate to complex, but necessary, methods to get the data we need for a FDC system and the role of metrology data on APC run-to-run controllers. Data and communication requirements for the next three to five years will also be discussed. The increased demands on the current process and metrology systems will increase as we begin to use new and alternative technologies to support more advanced APC strategies. [DOI: 10.1116/1.1380225]

I. INTRODUCTION

As the cost of developing new semiconductor devices and building new facilities, fast atom beams (Fabs), for their manufacture continues to increase, companies must continue to make every possible die yield. Making a die yield includes more than just making it electrically functional—it must be salable, preferably at the premium performance targeted so it provides the highest revenue.

Time-to-market is increasingly critical for the profitability of a company. Gone are the days of leisurely designing the next device. Today, markets expect and demand the latest products and services in ‘‘Internet time.’’ The need to quickly ramp production is more critical to meeting the fast shifts and changes in today’s market. State-of-the-art Fabs now must face the daunting challenge of maintaining ever more stringent controls for hundreds of manufacturing operations. Meanwhile, they must develop the means to rapidly and flexibly respond to the market demand and allow major changes in devices and processes to be developed, demonstrated, and implemented in high volume manufacturing in a short period.

Advanced process control (APC) supplies the capabilities needed to run today’s best Fabs. APC provides run-to-run (RTR) and fault detection and classification (FDC) as tools to control a Fab. APC RTR controllers change the metrology or process recipe used on the wafer to better control the outcome. FDC systems, on the other hand, do not attempt to change the recipe. Instead, these systems predict the need for human intervention, such as preventative maintenance, or to rapidly detect a catastrophic failure and automatically shut down the associated equipment to prevent further processing. Ready access to process and metrology equipment data (recipe parameters, tool-state parameters, and metrology results) is essential for successful APC RTR and FDC programs.

As wafer size increases, wafer cost increases. Each individual wafer may need to be treated as though it was its own process lot. Larger wafers will put an increased demand on the Fab for better and faster RTR and FDC control systems. This article demonstrates the need for easier access to equip-

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ment data and more reliable data in order to meet the needs of today's state-of-the-art Fabs using APC.

II. TYPES OF DATA REQUIRED

A variety of data is required for APC RTR controllers and FDC systems. Data comes from both the process and metrology equipment and is either used as collected or processed using automated algorithms to calculate desired values. All data can be categorized into three main areas: wafer state, process state, or tool state.

A. Wafer-state data

Wafer-state information is acquired by measuring a variety of properties and characteristics on the wafer itself. Fundamentally, wafer-state measurements are the most accurate reflection of the probable performance of the chips that are on that wafer. Typical metrology operations provide data on several properties including:

(1) film thickness and refractive properties;
(2) CD width;
(3) chemical stoichiometries;
(4) visual defects; and
(5) topography.

B. Process-state data

Process-state information is acquired by measuring properties and characteristics of the environment in which the wafer is being processed. Process-state measurements are an indirect measurement of what the wafer-state may eventually be. The process-state can be a very useful tool to keep the process in control and on target since it can be measured during the actual process instead of after several process steps are completed.

The need for in-line metrology measurements was driven by the need to recognize and correct process changes prior to finding them at sort and test. Similarly, the need to monitor critical process-states during the processing itself is driven by the need to better predict the subsequent wafer-state measurements. Typical measurements provide data on several properties including:

(1) chemistries present during a given process step; and
(2) absolute or relative changes in chemistries present during a given process step.

C. Tool-state data

Tool-state information is acquired by measuring the functional performance of the tools. These measurements provide only an indirect indication of what the wafer state may eventually be. They can be, however, one of the most important methods to single out specific tools operating off target. Accessing, monitoring, and controlling critical tool-state data is vital for process and metrology tools alike to avoid their use when conditions indicate misprocessing is likely. Some of the most common tool-state parameters measured and monitored include:

(1) temperature;
(2) pressure;
(3) fluid flow;
(4) time;
(5) rf power; and
(6) component status (open, closed, partially opened, on, off, etc.).

Tool-state parameters contained in recipes are the most common parameters modified by APC RTR controllers. In this respect, access to the tool state parameters is important, but more important is the ability to modify them remotely. Most RTR controllers used in high volume manufacturing perform recipe modifications between runs of lots containing multiple wafers. Some RTR controller, for example, epitaxial growth or deposition, may perform recipe modifications on a wafer-by-wafer basis. With larger wafers, however, the process recipe may need to be modified in between the individual wafers within a lot or during the processing of a single wafer as the norm.

III. DATA ACCESS

Currently, access to data can be a complicated and time-consuming task for APC systems. One needs to identify the best means to access the data, determine the proper data collection rate, and then ascertain the data format and content.

The most common means of accessing equipment data and information in the semiconductor is through the (SECSII/GEM) interface.[1–4] A typical installation of a FDC system using the SECSII/GEM communication is presented in Sec. III A.

Increasingly, companies are finding it necessary to access additional data not available through the SECSII/GEM interface or at sample rates often unachievable through the SECSII/GEM interface. A FDC using a custom data access system in described in Sec. III B.

A. Case Study 1; Typical SECII/GEM data access

Figure 1 is a schematic of Case Study 1 that uses Triant's MODELWARE system to collect and display individual tool parameters available through the SECS II interface. The data collector (DC) component from Triant has an active ''passthrough'' feature that allows it to request data from the tool at the same time that another host is controlling the tool. This feature is attractive for factories that already use the SECS II port for recipe and tool control and want to add trace data collection without disturbing the existing interface. By using a network terminal server, the SECS II data can be made available to any server. An application server is configured to read the terminal server data and convert it back to serial. On the application server, the DC component receives and transmits the SECS II data. At this point, DC is only acting as a SECS II passthrough server.

With a list of desirable tool variables to collect, DC is configured to insert into the SECS II stream requests for tool

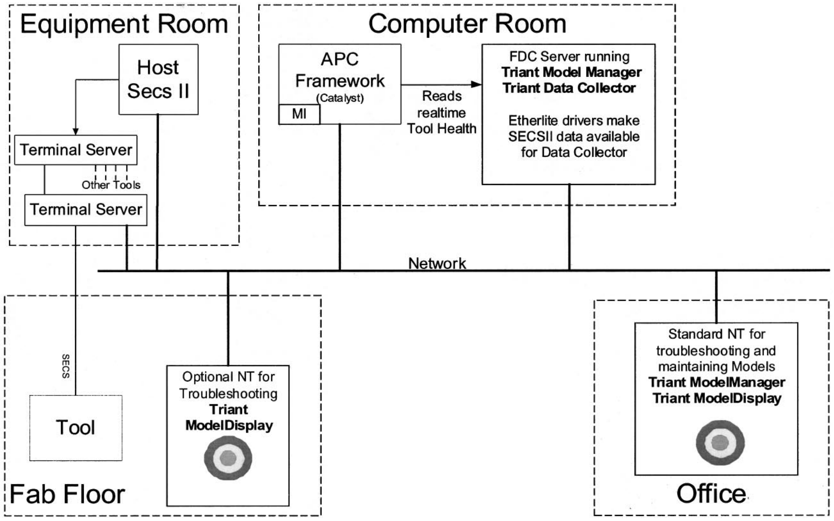

FIG. 1. Schematic of a typical system using SECS-based data communication and collection using Triant Technologies, Inc. MODELWARE is shown.

sible to collect trace data from the tool. The data is formatted for use with Triant's MODELWARE system. By using serial network terminal servers and an active passthrough, collection of any data available via the SECS II port is easily enabled without disrupting production.

B. Case Study 2; Custom data access

Figure 2 is a schematic of Case Study 2. This system also uses Triant's MODELWARE system to collect and display individual tool parameters. However, a more complicated, custom data access system had to be developed to supply the data.

Serial base SECS II protocol is limited by the RS232 bandwidth. Typically a request for a parameter can be made in 400–500 ms at 19.2 K baud. Most factories run SECS II at 9600 baud. That reduces the sampling rate to about 800 ms. For faster data rates, a faster protocol and/or medium must be used. The high speed message system (HSMS) standard, which is SECS II over a TCP I/P connection (Internet), can be used for much faster data rates. Unfortunately, HSMS is not readily available in established Fabs.

Tools usually have serial or parallel ports available that can be used to send trace data. In this case, a serial port was allocated for each chamber of a tool. Again, network terminal servers were used to transport the serial data using the network. The tool owner specified a custom binary data format that would contain all the available parameters of the tool. To ensure the fastest rate possible a minimal protocol was established to ensure data integrity. A custom program was developed to convert the high speed data into MODELWARE readable files. This allows us to re-use the entire MODELWARE infrastructure and only design a different method of collecting the data. The custom program is linked to the SECS II host program so that it essentially becomes an extension of the SECS II interface.

The experiences shown in Case Studies 1 and 2 illustrate that currently no single approach to accessing tool parameter

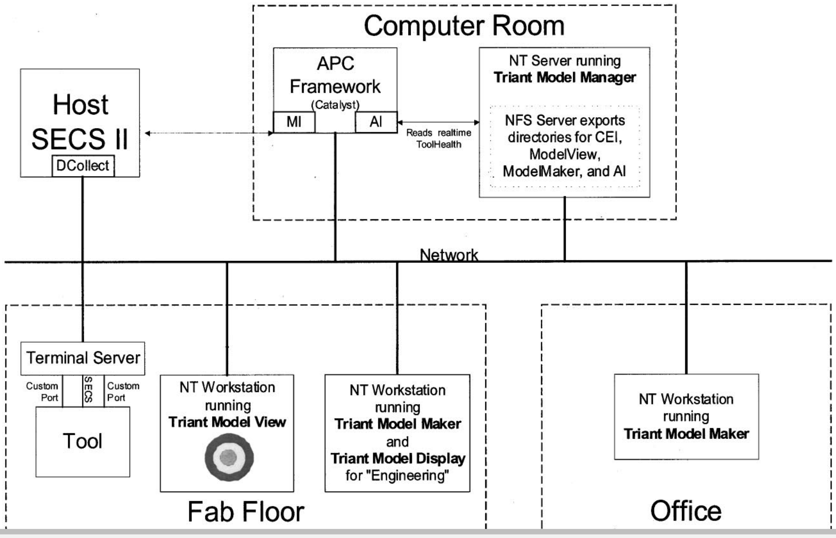

FIG. 2. Schematic of a custom data collection system and Triant Technologies, Inc. MODELWARE are shown.

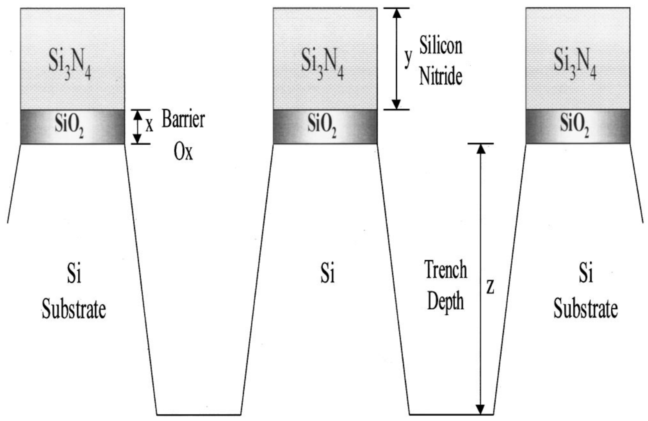

FIG. 3. Schematic of shallow trench isolation structure and film stack are shown.

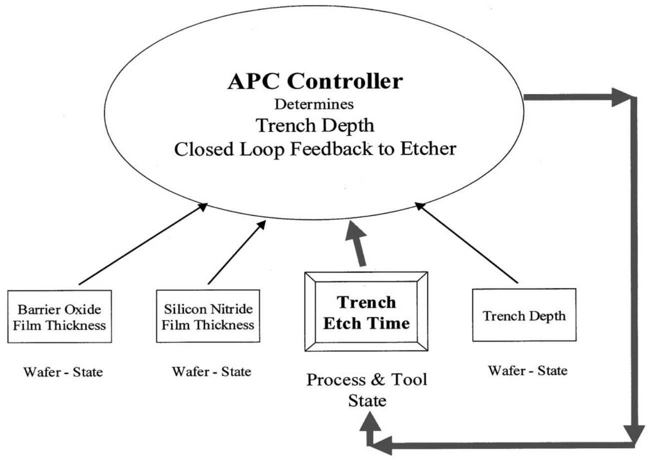

FIG. 4. Illustration of a shallow trench isolation advanced process control run-to-run controller is shown.

data meets all the needs of semiconductor end users. When all the data streams are readily available through existing, standard communications methods, simpler FDC systems can be deployed. When critical and targeted tool parameters are not available, more complex and sophisticated FDC systems must be developed, often times resulting in a very custom system for that particular application. The more complex and custom the FDC system is, the more costly it can be and the longer it may take to implement.

IV. DATA RELIABILITY

Loss of reliability in the data can result from noise. Noise can originate from variation in the process samples, the process and metrology equipment, and in the method of operation of the process and metrology equipment. The manner in which an APC controller compensates for the effects of normal variation in the process and samples is a critical and often a company confidential component of the APC controller. This article does not discuss the noise from normal variation in the process but instead focuses on metrology equipment-related noise.

The following case studies illustrate how erroneous data or the continued use of metrology systems that are not operating properly can adversely affect an APC controller. The failure to ensure reliable data used in APC could result in an automatically ‘‘correctly misprocessing’’ product.

A. Case study 3; Film thickness noise in shallow trench isolation etch APC controller

Figure 3 shows a schematic of a typical shallow trench isolation (STI) film stack, structure, and the associated measurements typically collected so a process engineer can periodically monitor the process. Essentially, the STI etch process must etch through a layer of silicon nitride (Si_3N_4), a layer of oxide (SiO_2), and then down into the silicon (Si) substrate. This trench is later filled with silicon oxide to provide greater insulation than that possible by the substrate alone. This in turn allows the device designers to greatly increase the density of transistors on each chip.

Typically an Etch engineer will manually monitor the STI etch process by taking a sample from the production line and performing a cross section scanning electron microscopy (SEM) to measure the trench depth. The process is also controlled by monitoring the trench depth in product wafers using a profilometer and by monitoring the etch rate of the individual films, simplified film stacks, or product.

Figure 4 shows the basic architecture of an APC controller that automates the ability to adjust the etch process more quickly and more frequently than the manual method. The controller responds to the required metrology data input and adjusts the etcher accordingly.

Figure 5 represents the normalized film thickness at the typical nine sites measured after the barrier oxide (SiO_2, BOX) growth process for four lots. The lots are labeled in the order in which they were processed and subsequently measured at the BOX.

Figure 6 represents the normalized film thickness at the typical nine sites measured after the silicon nitride (Si_3N_4, SiN) film deposition for the same four lots. A single site on Lot B was measured ten times thicker than all other sites on Lot B and the other three lots. This thickness was impossible under the process conditions. This ‘‘bad’’ data point repre-

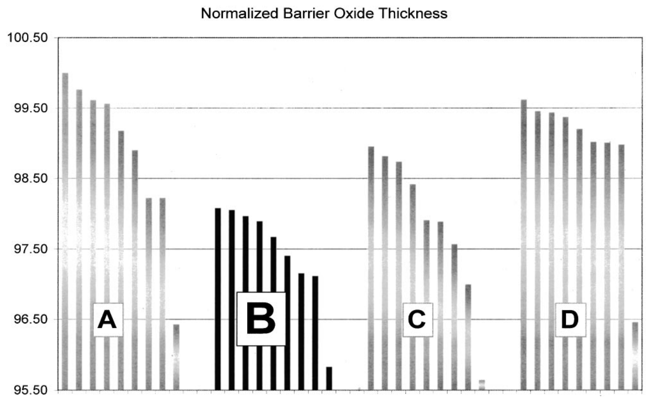

FIG. 5. Normalized BOX film thickness for four lots in Case Study 1 is shown.

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