New CD-SEM System for 100-nm Node Process

Osamu Nasu
Katsuhiro Sasada
Mitsuji Ikeda
Makoto Ezumi

OVERVIEW: With the semiconductor device manufacturing industry moving to the 100-nm node era, CD-SEMs (critical-dimension scanning electron microscopes) need to have further improved CD measurement reproducibility as well as observation performance. In addition, the demand is growing for functionalities applicable to new fabrication processes, such as ArF-resist and low-k insulating-layer processes, which have been developed to achieve higher levels of integration into microstructures. The Hitachi Model S-9260 CD-SEM system has been developed to meet the requirements of these new fabrication processes. Having the following features, it can provide a CD measurement environment suitable for fabricating next-generation semiconductor devices: (1) Excellent observation performance based on the electron optical design common in the S-9000 Series, (2) Enhanced CD measurement reproducibility, throughput, and other basic performance capabilities, (3) Improved process-variation monitoring, (4) Instrument performance maintenance/control support functions, and (5) New process application functions such as those for beam-tilt observations, surface-charged-specimen measurements, and ArF-resist measurements.

INTRODUCTION

AROUND 1985, mass production of 1-Mbit DRAM (dynamic random access memory) devices based on a 1.3-µm design rule started in the semiconductor device manufacturing industry. Since then, to inspect pattern dimensions, CD-SEMs using electron-beam technologies have been adopted in lieu of optical microscopes.

As a CD-SEM can measure the ultrafine patterns formed in semiconductor-fabrication processes, it enables producing high-quality semiconductor devices. At present, semiconductor devices are mass-produced based on a 0.13-µm design rule for higher integration density. In the near future, the design rule in mass production of microchips will be 0.1 µm or less. According to the recent International Technology Roadmap for Semiconductors (ITRS) report, introducing technical trends in semiconductor-fabrication processes, the market needs for CD-SEM systems can be enumerated as below:

• Measurement repeatability (static)	2 nm (3 sigma)
• Acceleration voltage	300 – 1,600 kV
• Resolution	3 nm
• Throughput	65 wafers/h
• MAM time	Less than 5 s
• Open type 3 cassette port	(SMIF 2 port)
• Software	Version 16
• Safety standard	SEMI S2-0200 compliance

MAM: move, acquire, measure
SMIF: standard mechanical interface
SEMI: Semiconductor Equipment and Materials International

Fig. 1 —New Hitachi CD-SEM Model S-9260.
The latest model of the S-9000 series CD-SEM meets the needs of semiconductor process-development and mass production for sub-0.1-µm process nodes.

(1) Observation of high-aspect-ratio patterns and high-accuracy stable measurement in a short time.
(2) Application to fabrication processes based on a 0.1-µm design rule or less.
(3) Detection of variations in fabrication processes by measuring pattern-configuration variations.
(4) Unsupervised automatic operation to increase productivity.

Presented here is a new CD-SEM S-9260[1] model that has been developed to meet the market needs mentioned above. The future prospects of CD-SEM systems will also be discussed in this paper.

FEATURES OF MODEL S-9260 CD-SEM

Excellent Observation Performance

The electron optical system of the Model S-9260 CD-SEM has a 3-nm image resolution, which is applicable to lines/spaces and hole patterns of less than 0.1 µm. Figs. 2 and 3 show examples of observations of the model.

Improved Basic Performance

The Model S-9260 has an improved basic performance, as shown in Fig. 1.

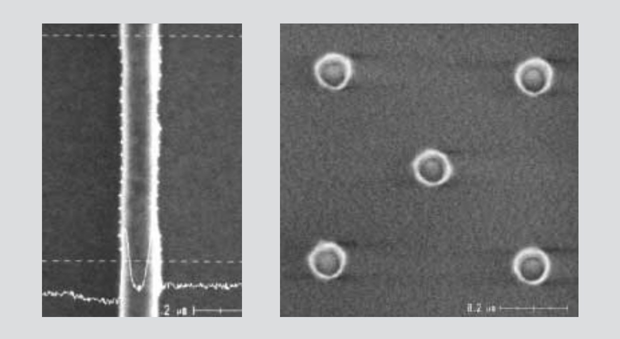


Fig. 2—Observation Examples of Ultrafine Patterns on Model S-9260.
Observation examples of a 69-nm wide line and 64-nm diameter holes [EB (electron beam) resist pattern is 0.5 µm thick].

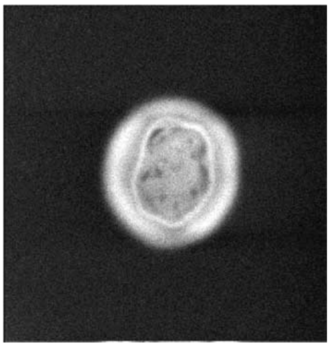


Fig. 3—Observation Example of a High-aspect-ratio Hole on Model S-9260.
A hole with an aspect ratio of 20 formed on a 2.0-µm-thick BPSG (boron phosphorous silicate glass) film is imaged. The bottom of the hole is clearly visible.

CD measurement reproducibility

The CD measurement reproducibility has been enhanced by reducing specimen contamination; a vacuum specimen chamber ensures higher cleanliness and the pattern detectability in the image recognition has been improved. In CD measurements that are repeated ten times, a 2-nm reproducibility value can be achieved (3-sigma standard deviation).

Enhanced throughput

A new type of transfer robot mechanism is used to shorten the wafer-handling time in atmospheric air. Furthermore, a high-speed image processor and an image-processing algorithm have been developed to achieve a 65-wph (wafers per hour) throughput (in 5-point measurements on Hitachi standard wafer specimens).

Process-variation Monitoring

Early detection of process variations is essential for production yield control, thus CD-SEM systems should also contain this function. The Model S-9260 has formula-editor and beam-tilt observation functions that enable detecting process variations early and controlling them easily.

Formula-editor function

The formula-editor function allows users to measure plural dimensional values of an object pattern under test and to monitor variations in configuration of the object pattern arithmetically by using the measured dimensional values. Table 1 shows setting

TABLE 1. Setting Examples of Formula Editor Function

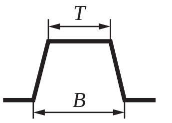
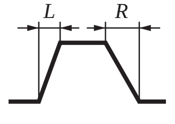
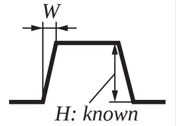
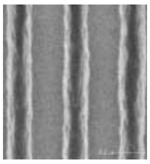
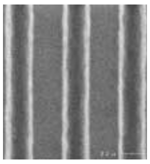
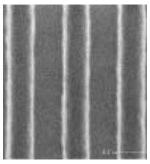
Item	Duty ratio	Symmetry property	Side-wall angle
Shape			
Equation	T/B	$\|L-R\|$	$\mathrm{Tan}^{-1}(W/H)$

TABLE 2. Example Application of Formula-editor Function

SEM image			
Bottom	0.203 µm	0.199 µm	0.216 µm
T/B	0.400	0.565	0.678

examples of the formula-editor function, and Table 2 shows an application example.

Arbitrary calculations can be defined for values such as the line-pattern bottom width, top-bottom width ratio, left and right inclination dimensions, and the inclination angle. Using calculation values that are optimal for an object pattern enables effectively detecting variations in the pattern configuration.

In pattern recognition, the ratio of top to bottom (T/B) is more responsive than the width of bottom, and hence the former is more useful for detecting process variations.

Beam-tilt observation function

The beam-tilt-observation function is designed to deflect the primary electron beam to a microstructure pattern so the user can inspect the configurations of the side walls and the regions near the hole bottoms on the pattern, which would otherwise be difficult to observe. In the Model S-9260, the primary electron beam can be tilted in eight directions.

The process variation data attained with the functions mentioned above is applicable to APC (advanced process control) for semiconductor-fabrication facilities such as pattern-exposure equipment. Thus, process variations can be reduced more efficiently.

Instrument-performance Maintenance/Control-support Function

The Model S-9260 is provided with an optical-performance-monitor function that enables the user to check the current condition of the optical mechanisms. With this function, the user can judge the axial adjustment timing. The Model S-9260 also has an automatic alignment function for enabling electrical axial adjustment, which will improve self-diagnostic testability and maintainability.

Optical-performance-monitor function

The optical-performance-monitor function is incorporated in the Model S-9260 for overall monitoring in axial-adjustment and astigmatism-correction errors. The dimensional value calibration specimen “microscale” unique to Hitachi is available as the standard reference. The microscale is a reference device on which a line-space pattern is formed with an accurate pitch (240 nm) by laser interference fringe exposure and silicon monocrystal isotropic etching. The X- and Y-direction images of the microscale are Fourier-transformed to evaluate the image quality. The calculated value is indicated as a ratio to pre-recorded standard image data. The time-course variation can also be controlled by using a time-series graph.

Automatic alignment of electron optics

Conventionally, users need to manually adjust axially the electron optics at regular intervals or whenever the image quality degrades. The Model S-9260 is equipped with an automatic alignment function based on image processing, so it can perform operator-independent accurate axial adjustment in a short time.

Supporting New Fabrication Processes

Wafer-charge-correcting function

Various wiring materials, including low-k materials, and several fabrication processes have been used in recent years, so as a result wafer surfaces have become more likely to be charged. In some cases, charging at 200 to 300 V can cause problems, such as unsuccessful automatic focusing and CD measurement errors, due to unintentional changes in the objective

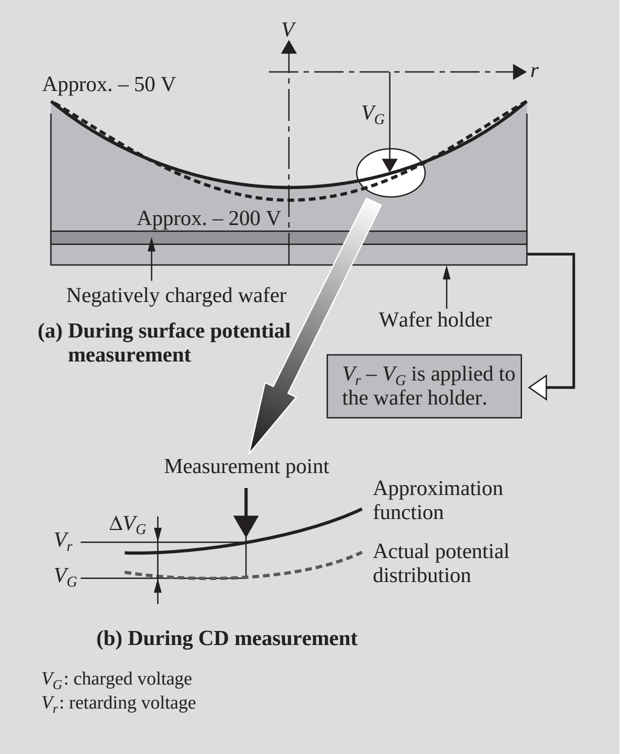


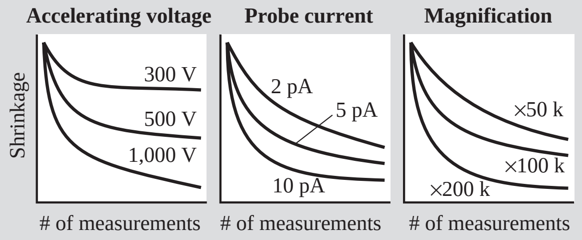
Fig. 4—Scheme of Wafer-charge Correction.
A charge voltage on the wafer surface is measured by using an electrostatic voltmeter circuit, and the charge-voltage distribution over the entire wafer surface is approximated with a radius “r” function. At an arbitrary point in the CD measurement, a voltage of $V_r - V_G$ *is applied to the wafer substrate to correct the wafer-surface potential with a retarding voltage* V_r.

lens' optical magnification.

To prevent these problems, the Model S-9620 is provided with a wafer-charge-correcting function[2]. Using an electrostatic probe mounted on the wafer-transfer path, the amount of surface charge is measured during the wafer-transfer operation, and the voltage corresponding to the surface charge is superimposed on a retarding voltage. This way the wafer-surface charge can be corrected without causing an adverse effect on the throughput. Fig. 4 shows a scheme of the wafer-charge correction.

ArF resist application package

An ArF resist intended for lithography with ArF light at a 193-nm wavelength that is produced by using acrylic resin as a base material is excellent in resolution but problematic in SEM/etching resistance. During an observation the ArF resist noted above is likely to shrink due to electron-beam exposure (see Fig. 5). Since the degree of shrinkage of the ArF resist depends on the energy and dose of the electron-beam exposure, they should be minimized to suppress the shrinkage. Fig. 6 shows an example of CD measurement results.



(a) Accelerating voltage dependency **(b) Probe current dependency** **(c) Magnification dependency**

Fig. 5—Relationship between CD Measurement Parameters and Degree of Shrinkage.
The Model S-9260 has an ArF resist-pattern-observation mode. In this mode, limitations are imposed on (1) accelerating voltage, (2) probe current, and (3) measurement magnification. Line-space patterns scanned at different magnifications in both the measurement direction (X) and the orthogonal direction (Y).

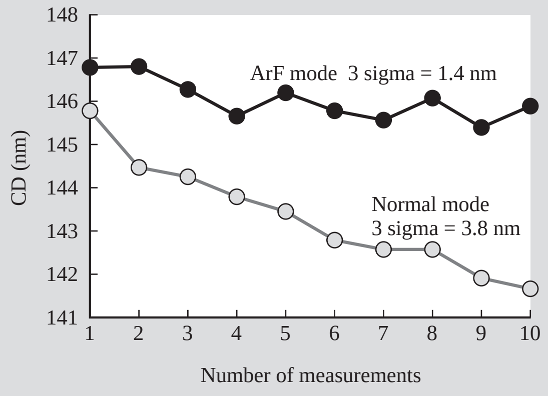


Fig. 6—Results of 10-times Repeated Measurements of ArF Resist Pattern.
In 10-times repeated measurements by scanning at different magnifications for (a) to (c) of Fig. 5 and measurement directions, the pattern shrinkage was 1.4 nm.

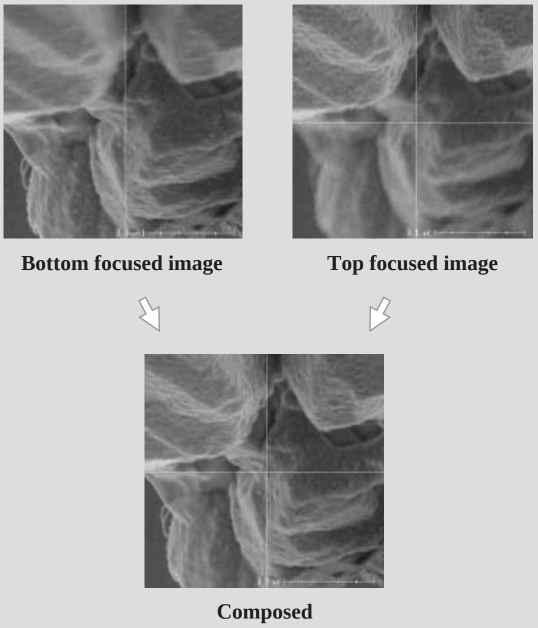


Fig. 7—Application Example of Multi-focus Function.
A clear SEM image can be obtained by composing multiple images acquired at several focal points and by using an advanced image-processing technology.

Other Features

In addition to the foregoing, the Model S-9260 has a variety of new functions. A multi-focus function, for example, facilitates observing specimens that have a large step difference. Here, in-focus areas only are taken from multiple images that have different focal point positions, and the image is synthesized selectively (see Fig. 7). Thus, the multi-focus function enables high-magnification observations of the entire visual field of a specimen that has a step difference exceeding 10 μm.

CONCLUSIONS

In semiconductor-device fabrication based on a 0.1-μm design rule or less, CD-SEM systems need to measure finer patterns highly accurately at a high speed and the systems need to be applicable to new kinds of materials and processes.

The Model S-9260 CD-SEM system described above is an advanced instrument that has features that meet the requirements for fabricating next-generation semiconductor devices based on a 0.1-μm design rule or less.

We will continue research and development further to achieve an even higher performance and to realize three-dimensional configuration measurements, enhanced process control functions, automatic measurements linked with CAD data, and other new functions.

REFERENCES

(1) R. Fukaya, et al., “On CD SEM S-9260,” Proc. of LSI Testing Symposium (Nov. 2001) in Japanese.
(2) K. Sasada, et al., “Electron Beam CD Measurement System,” Proc. of Nano-Beam Symposium (Dec. 2001) in Japanese.

ABOUT THE AUTHORS

Osamu Nasu
Joined Hitachi, Ltd. in 1990, and now works at the Electronics Systems Design Department 1, Naka Division in the Design & Manufacturing Group of Hitachi High-Technologies Corporation. He is currently engaged in the development of a scanning electron microscope for semiconductor manufacturing. Mr. Nasu can be reached by e-mail at nasu-osamu@naka.hitachi-hitec.com.

Katsuhiro Sasada
Joined Hitachi, Ltd. in 1984, and now works at the Electronics Systems Design Department 1, Naka Division in the Design & Manufacturing Group of Hitachi High-Technologies Corporation. He is currently engaged in the development of a scanning electron microscope for semiconductor manufacturing. Mr. Sasada can be reached by e-mail at sasada-katsuhiro@naka.hitachi-hitec.com.

Mitsuji Ikeda
Joined Hitachi, Ltd. in 1985, and now works at the First Department, the System Research System Unit of the Hitachi Research Laboratory. He is currently engaged in the development of the image processing architecture and pattern recognition technology. Mr. Ikeda is a member of the Information Processing Society of Japan (JPSJ) and the Institute of Electronics, Information and Communication Engineers (IEICE), and can be reached by e-mail at ikeda@gm.hrl.hitachi.co.jp.

Makoto Ezumi
Joined Hitachi, Ltd. in 1989, and now works at the Beam Technology Center of Naka Division in the Design & Manufacturing Group of Hitachi High-Technologies Corporation. He is currently engaged in the development of the core technology used for electron beam instruments. Mr. Ezumi is a member of the Japan Society of Applied Physics (JSAP), and can be reached by e-mail at ezumi-makoto@naka.hitachi-hitec.com.