Scanning Surface Inspection System with Defect-review SEM and Analysis System Solutions

Hideo Ota
Masayuki Hachiya
Yoji Ichiyasu
Toru Kurenuma

OVERVIEW: Data obtained from wafer-surface inspection tools are limited to defect maps, defect number, etc. In any case, in order to swiftly execute measures to decrease the amount of defects, it is very important to determine where the defects are being generated. Accordingly, more concrete information on defects, such as shape and constitution data, is becoming more necessary. Hitachi High-Technologies Corporation is therefore offering a line-up of wafer-surface defect inspection tools and review scanning electron microscopes, and Hitachi Kenki FineTech Co., Ltd. is offering a line-up of atomic-force microscopes. In the present work, a system of improving yields by providing surface-analysis information about unpatterned silicon wafers—called "smart root cause analysis"—was developed. From now onwards, although defect observation based on the output coordinates from surface inspection of unpatterned silicon wafers is extremely difficult owing to a lack of an alignment basis, the developed system can address this difficulty and make a key contribution to crucial defect countermeasures with high efficiency.

INTRODUCTION

APPLICATIONS of unpatterned silicon-wafer substrates have two broad classifications. The first (fundamental) application is the inspection for starting material before a circuit pattern is formed on the substrate surface, and a semiconductor device is processed. In the second, defects generated by semiconductor device-processsing equipment—namely, film-deposition equipment, etching tools, CMP (chemical-mechanical polishing), and cleaning equipment—are investigated. In the former case, the wafer is distinguished as a "prime wafer," and in the

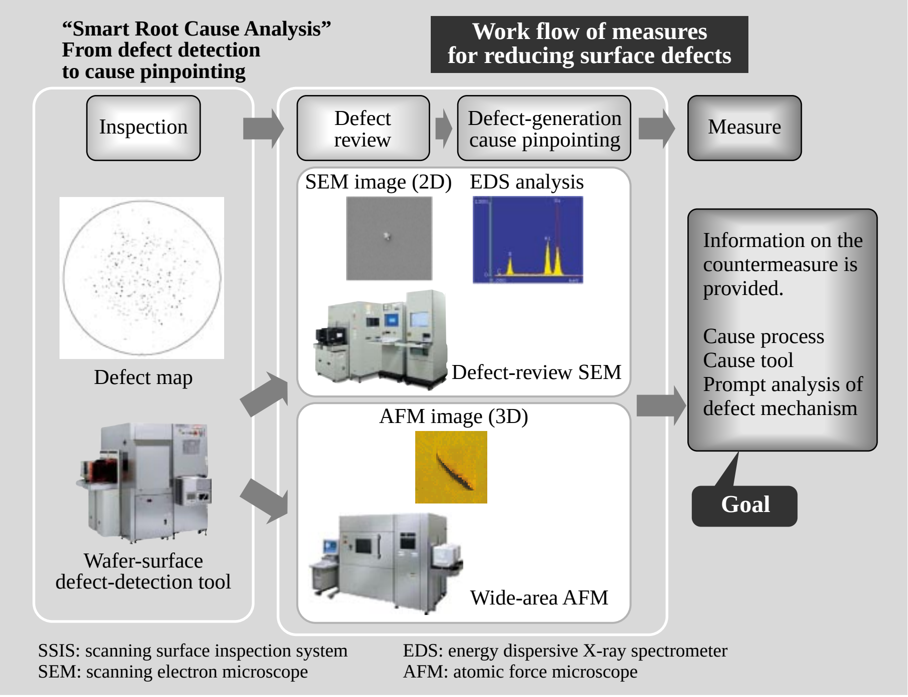

Fig. 1—Linkage of Surface Inspection System and Defect-review SEM.
By defect-review SEM based on defect-location coordinates obtained from SSIS and by observation, classification, and EDS elemental analysis or 3D observation with AFM, data that contributes to improving yields of customers' production systems are provided.

latter case, the wafer is distinguished as a "test wafer," a "process monitor wafer" or a "dummy wafer."

As regards the amount of test wafers consumed, defect measurement using test wafers is widely performed with about the same number of wafers as platform wafers used in processing semiconductors. In line with the trend of device scaling-down, the object size in required defect measurement is getting smaller year by year, and detection and analysis of defects are getting even tougher.

Concerning the defect-analysis method used for test wafers, analyses of wafer-transport particle and process-generated particle are carried out. Analysis on wafer-transport particle PWP (particles per wafer pass) is the operation of investigating particle that becomes attached to a wafer when it is in actual processing equipment and when it is transferred between processes. Analysis on process-generated particle PIDs (process-induced defects) is the operation of investigating defects generated after wafer processing such as moving wafers under actual process conditions such as film formation (i.e. dummy deposition) (see Table 1).

In the rest of this paper, equipment for detecting wafer defects is described, and the above-mentioned analysis methods are explained (see Fig. 1).

TABLE 1. Object of Surface-defect Analysis, and Object Unpatterned Wafer and User
Surface-defect analysis requires many users involved in semiconductor production.

Aim	Object unpatterned wafer	User
PWP measurement (wafer transportation dust)	Bare wafer	Device manufacturer
PID measurement (process generated dust)	Coated wafer	Equipment and materials supplier
Surface-defect measurement of silicon wafer	Bare wafer	Wafer manufacturer

PWP: particle per wafer pass PIP: process-induced defect

SSIS (SCANNING SURFACE INSPECTION SYSTEM)

As regards defects on unpatterned silicon wafer substrates, the principle of laser scattering is applied in detecting the defects. The detection principle utilized in Hitachi High-Technologies's SSIS is shown schematically in Fig. 2. This defect-detection principle is as follows: a laser is illuminated onto the wafer surface from above, scattered light from a defect is collected by a receiving lens, and the scattered light is converted to an electrical signal by a detector. The wafer is set on the rotating stage, and by moving the stage in the radial direction while it rotates, the whole wafer surface can be inspected at high speed. And by fixing an encoder to the stage, positional data of the wafer defect can be obtained.

The attainable sensitivity of our latest model of SSIS is 36 nm on a bare wafer surface.

LINKAGE OF SSIS AND DEFECT-REVIEW TOOLS

Defect-review SEM

Although information obtained from SSIS is restricted to defect maps, defect number, etc., in order to swiftly carry out measures for reducing defects, it is important to find out where the defects were generated. This location is thus determined by defect inspection. Based on the location coordinates obtained from this inspection, defect observation by high-

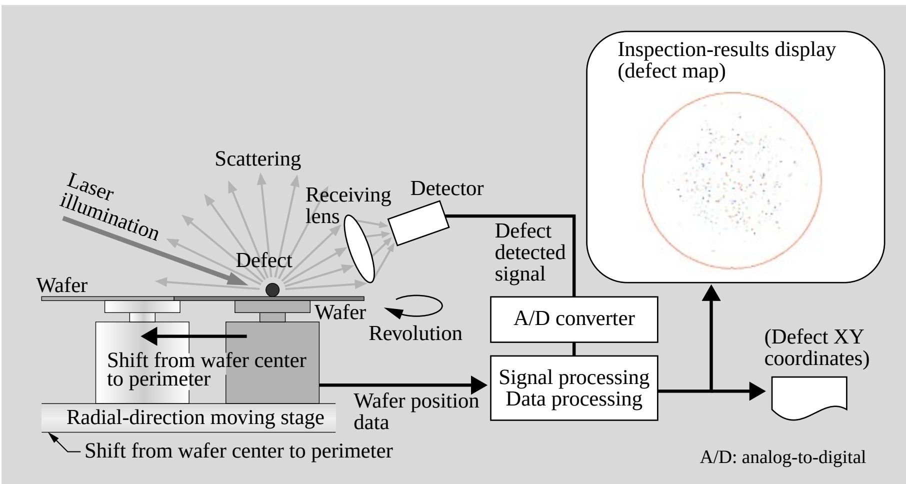

Fig. 2—Overview of Detection by SSIS.
A laser is illuminated on the bare wafer, and defects are detected at high speed.

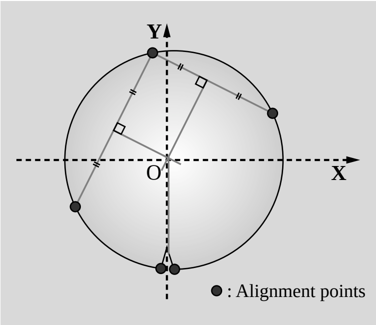

Fig. 3—Example of Alignment of Bare Wafer.
A total of five points (three points on the periphery and two at the mouth of a V-notch) are aligned.

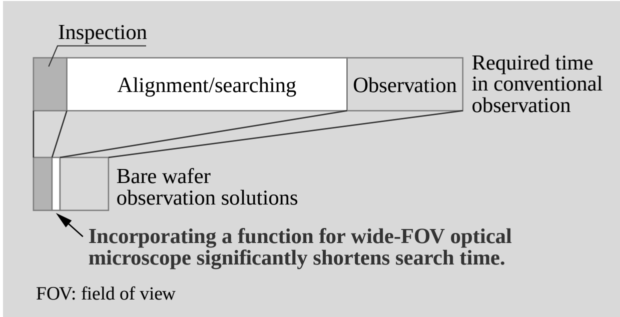

Fig. 4—Making Observation of Bare Wafer Surface More Efficient by Wide-view Optical Microscope.
Observation efficiency is significantly improved (about 100 times).

magnification tools, such as SEM (scanning electron microscope), is an extremely effective approach.

Under these circumstances, Hitachi's latest defect-review SEMs were developed for reviewing—at high efficiency in a short time—the vast amounts of inspection results obtained from the improved-sensitivity defect-inspection tools in use over recent years.

Problems Regarding Defect Review of Unpatterned Wafers

The four main methods used in SSIS and defect analysis are given as follows:

(1) Defect detection by SSIS, and output of defect-location coordinates
(2) Coordinate matching alignment of SSIS tool and review SEM (see Fig. 3)
(3) Defect search and observation by review SEM
(4) Defect analysis by EDS (energy dispersive X-ray spectrometer) (i.e. elemental analysis)

While these methods are recognized as effective for defect analysis, in execution of defect observation, there is a barrier to reacquiring defects by the methods on the SEM side, i.e. (2) and (3) above.

In the case of a patterned wafer, a chip die origin is used as an alignment point, and since the alignment can relatively easily come off, defects are easy to review.

However, with an unpatterned silicon wafer, since a unique alignment method is used for fixing the profile of a wafer, it is difficult to get high-precision matching between the coordinate system on the inspection-tool side and that on the review SEM side.

Wide-FOV Optical-microscope Function

To address the above-described issues, Hitachi High-Technologies has fitted its defect-review SEMs with a function for wide-view optical microscope, thereby vastly improving the efficiency of observation of bare wafers with large alignment error (see Figs. 4 and 5).

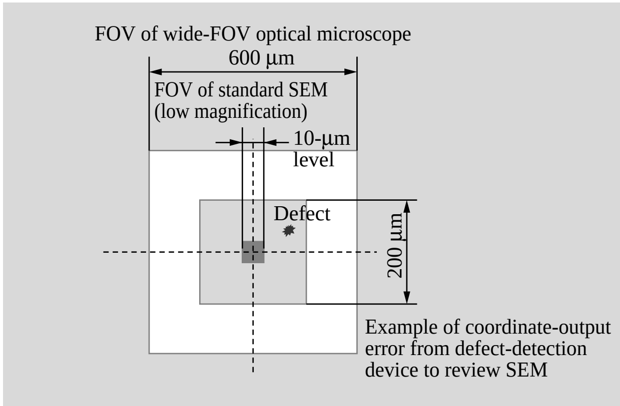

Fig. 5—FOV of Wide-FOV Optical Microscope.
Defects can be searched for over a wide-FOV.

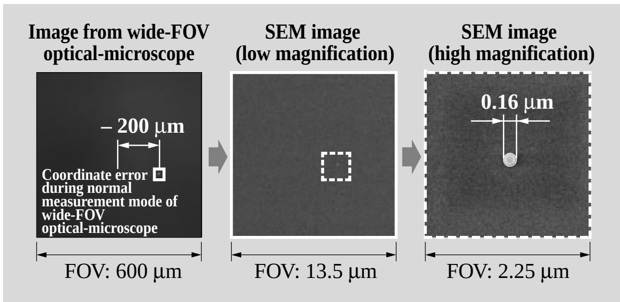

Fig. 6—Example of Defect Observed by Using Wide-FOV Optical-microscope Function.
First, defects at the macro level are found by optical microscope, then micro observations are done by SEM.

It is currently possible to automatically pick up defects with a size of 70 nm in a 600-μm^2 FOV (field of view) on a wafer surface. This gives enough leeway for a condition where detection of total alignment error with standard defect-detection tools of less than 200 µm, and matching with each detection tool are possible (see Fig. 6).

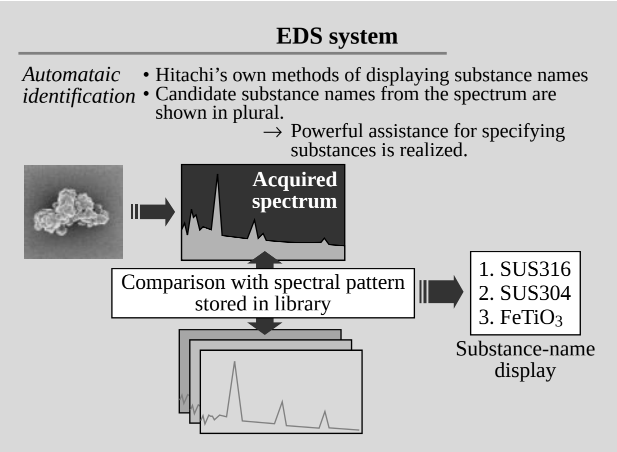

Fig. 7—Principle of Pinpointing Defect Material by EDS.
The obtained spectral pattern is compared with one recorded in a library. Each material is then shown in order of high concordance ratio.

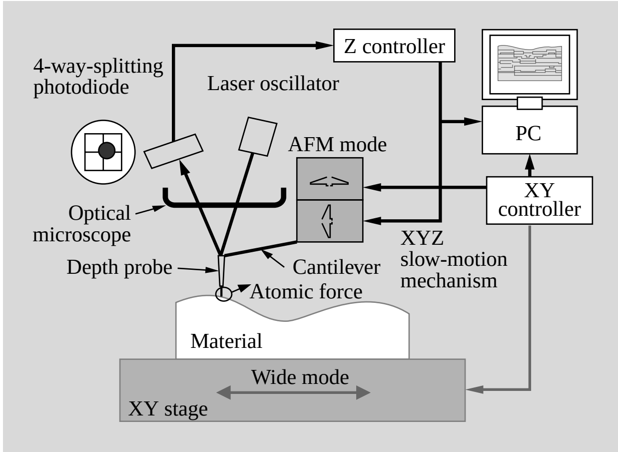

Fig. 8—Block Diagram of Hitachi's AFM
While detecting atomic force corresponding to the spring constant of a cantilever, the surface of the material is scanned.

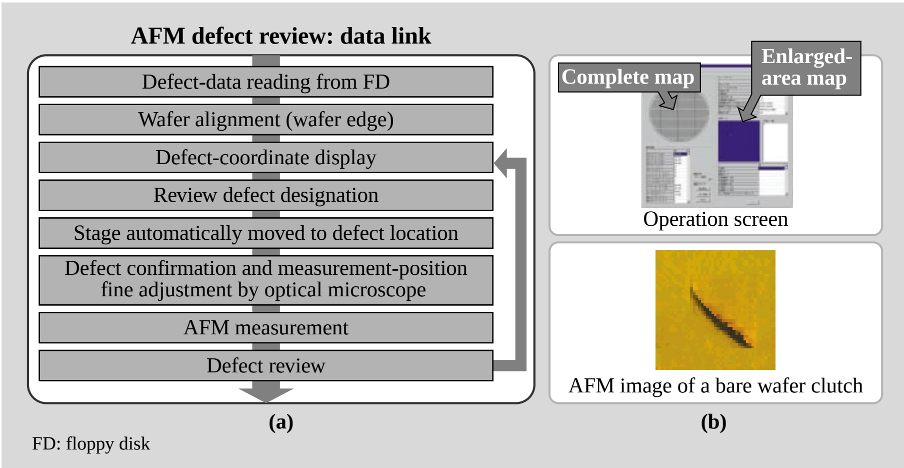

Fig. 9—Surface-defect Analysis by Hitachi's AFM (a), Example of 3D Surface Observation (b).
The procedure for surface analysis of a bare wafer, the operation screen, and an example of void-defect output are shown.

Defect Elemental Analysis by EDS

In regards to Hitachi's defect-review SEM series, as an analysis function, where elements included in a defect are identified, EDS can be fitted optionally. An electron beam is irradiated onto the target defect, the generated X-ray energy is detected, and the elements in the defect are identified. In addition, by comparing the detected elemental composition with substances recorded in a library, the physical substance of the defect can be identified. This function is a powerful way of examining the generation of defects in conjunction with classifying them (see Fig. 7).

SURFACE ANALYSIS BY AFM

3D Surface Shape Analysis

Although surface defects can be conveniently reviewed by defect-review SEM, in the case of observation of 3D surface shape, use of AFM (atomic force microscope) can achieve resolution in the order of 0.1 nm in the vertical direction (see Fig. 8).

As the objects of surface observation by AFM, micro-scratching formed during CMP, COP (crystal-originated pit) formed during processing of silicon wafers, and typical void defects with openings of less than 100 nm are often mentioned.

Linking Coordinates of SSIS and AFM

By equipping a coordinate-link function with an AFM, it is possible to observe defects identified by SSIS by AFM. The analysis procedure is shown in Fig. 9 (a). Moreover, examples of the operation screen and the AFM output image are given in Fig. 9 (b).

Haze Data and AFM

In regards to SSIS, as well as detection of point defects on a surface, a function for mapping surfacedispersion data of parts without defects is available. Haze information—the processed scattering signals that are lower than the minimum detection sensitivity—is utilized through a linkage with high-resolution AFM, so even more detailed analysis of a surface is possible. Further study on use of haze information is our future challenge.

CONCLUSIONS

This paper described defect detection of unpatterned wafers by integration of inspection and analysis tools and analysis methods. From now onwards, along with the continuing scaling down of devices, thorough investigation of the generation cause of defects—which have an impact on device yields—will become even more difficult. Along with improving the function of individual machines in our line-up of inspection and analysis tools, Hitachi Group will enhance its development of applications that combine these tools in order to meet the future needs of the information society.

REFERENCES

(1) H. Koyabu et al., "In-line Atomic Force Microscope for Semiconductor Process Evaluation", *Hitachi Hyoron* **84**, pp. 271-274 (Mar. 2002) in Japanese.

(2) M. Nozoe et al., "Inspection and Analysis Solutions for High-quality and High-efficiency Semiconductor Device Manufacturing," *Hitachi Hyoron* **86**, pp. 465-470 (July 2004) in Japanese.

ABOUT THE AUTHORS

Hideo Ota

Joined Hitachi Electronics Engineering Co., Ltd. in 1979, and now works at the Application Technology Department, the Semiconductor Process Control Systems Sales Division, Hitachi High-Technologies Corporation. He is currently engaged in the marketing of semiconductor inspection system. Mr. Ota is a member of The Japan Society of Applied Physics (JSAP), and can be reached by e-mail at: ohta-hideo@nst.hitachi-hitec.com

Masayuki Hachiya

Joined Hitachi Electronics Engineering Co., Ltd. in 1980, and now works at the Optical Inspection Systems Design Department, Naka Division, the Nanotechnology Products Business Group, Hitachi High-Technologies Corporation. He is currently engaged in the development of wafer inspection system, and can be reached by e-mail at: hachiya-masayuki@naka.hitachi-hitec.com

Yoji Ichiyasu

Joined Hitachi, Ltd. in 1984, and now works at the Application Technology Department, the Semiconductor Process Control Systems Sales Division, Hitachi High-Technologies Corporation. He is currently engaged in the marketing of semiconductor inspection system, and can be reached by e-mail at: ichiyasu-yoji@nst.hitachi-hitec.com

Toru Kurenuma

Joined Hitachi Construction Machinery Co., Ltd. in 1982, and now works at the Design Department II, the Development & Production Division of Hitachi Kenki FineTech Co., Ltd. He is currently engaged in the design and development of an AFM system. Mr. Kurenuma is a member of The Japan Society of Mechanical Engineers (JSME), and can be reached by e-mail at: kurenuma82@hitachi-kenki.co.jp