Semiconductor Inspection System for Yield Enhancement

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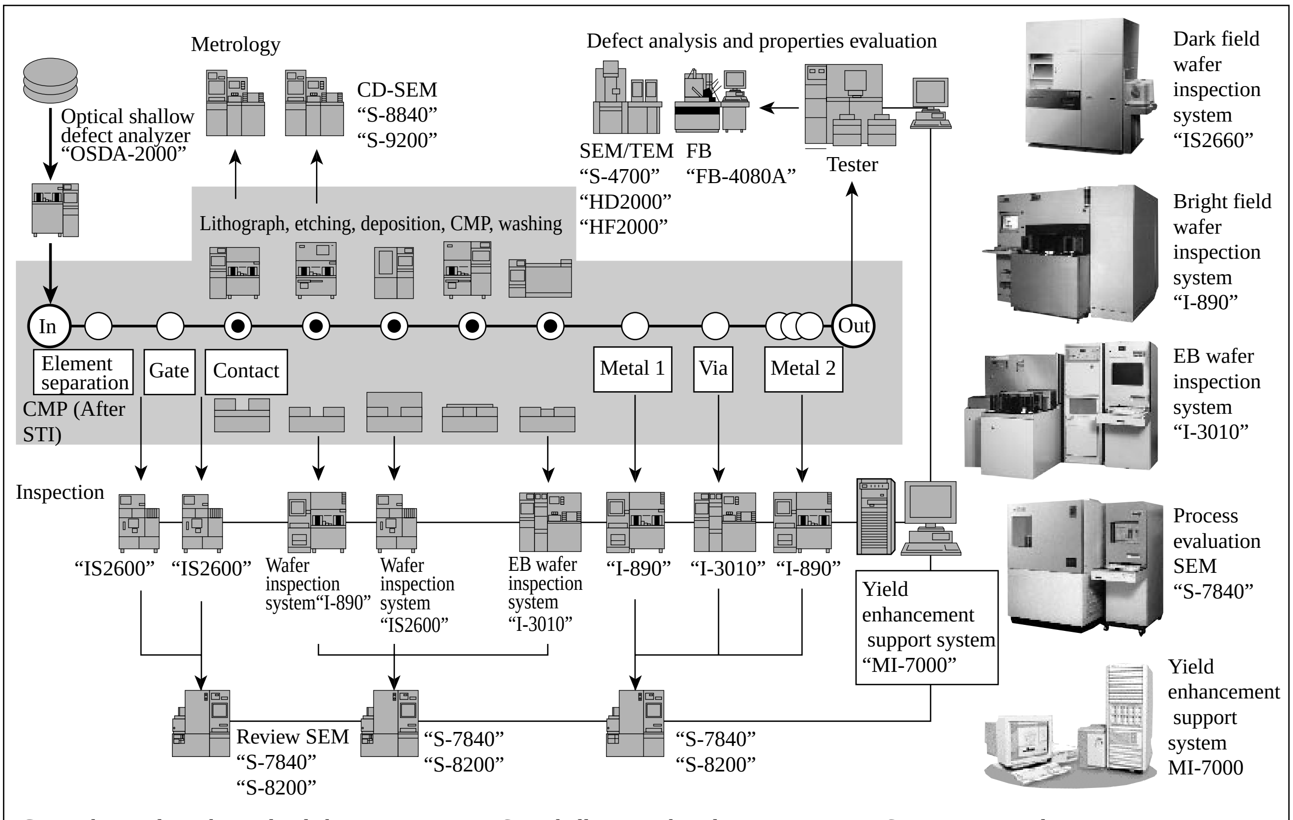
OVERVIEW: As the American SIA (Semiconductor Industry Association) technology roadmap shows, semiconductor devices are moving toward higher circuit integration and density. There is also a need for device inspection equipment and systems which meet high performance requirements. Hitachi proposes a total inspection system that enables efficient operation at an appropriate investment. This inspection system includes both high sensitivity and high throughput equipment as well as analytical systems for efficient analysis of yield parameters.

INTRODUCTION

FOLLOWING the Ameriacan SIA (Semiconductor Industry Association) technology roadmap, development of devices of higher integration and density has increased every year (Fig. 2). In 1994 it was forecasted that the technology node for 130 nm would be achieved in 2004. Today, however, development is already underway toward the technology node for 180 nm – 130 nm. The SIA roadmap in the past suggested that a possibility of 100



CMP: chemical-mechanical polishing STI: shallow trench isolation SEM: scanning electron microscope

Fig. 1— Hitachi Semiconductor Inspection System — Supporting Yield Enhancement on Semiconductor Production Line.
The inspection/evaluation system operated on the semiconductor production line can be broadly divided into: (1) Mainly in-line inspection; (2) Mainly on-line defect analysis and evaluation of process properties; and (3) Mainly line-width measurement centering on lithography process. Hitachi proposes a 'Total System' that not only supplies the individual equipment for the above inspection/evaluation, but also integrates and controls all device data.

nm or smaller was expected around 2003 as shown by the broken line in Fig. 2, and that continued development toward finer processing was anticipated.

In the field of optical patterning (steppers) which is a fine processing technology, investigations of optical limitations have become important development themes. Multi-layer and complex structures have been introduced. Associated with planarization technology, much more complex multi-layer wiring has been developed. In conjunction with improvements and developments of process technologies, a new breakthrough, which is an important assignment for semiconductor production business, has been required since improvements in production and quick yield enhancement are directly connected to profitability. For better productivity, large diameter wafers (300 mm) have been studied. With respect to yield enhancement, a method must be found, which allows better yield despite of higher integration and density as well as complicated structures. For this purpose, a new total system which integrates and allows operation of various semiconductor inspection/evaluation equipment synergistically. The operation of the total system needs to be studied in terms of investment.

Inspection systems, for example, were developed in association with integration and density of devices. Taking advantage of each equipment, the inspection systems have been developed for higher performance or in a form of a new equipment. Each of these developments resulted in cost increase up to this time. There is a new trend of requirements generated from users for correcting the cost increase based on their experience and improving the performance of their existing equipment using new ideas. Similarly, a use of various equipment in their optimum conditions and a proposal of a cost-efficient total inspection system have become another important subject. This report introduces the Hitachi's inspection systems for yield enhancement paving the way to the age of 0.1-μm devices.

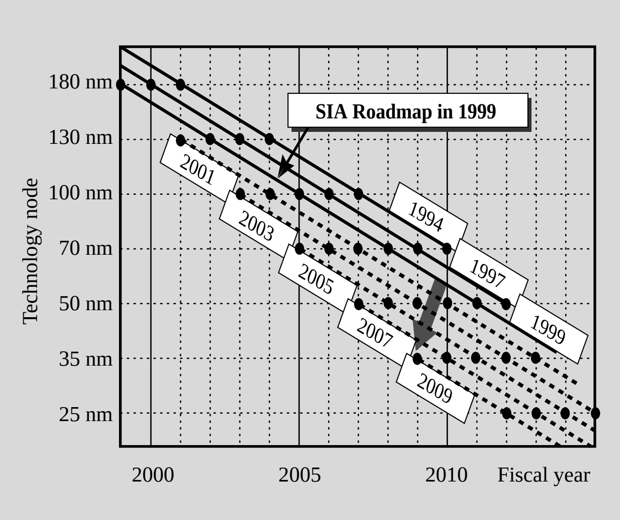


Fig. 2— American SIA's Technology Roadmap.
The figure shows a roadmap formed by plotting the technology nodes forecast each fiscal year. Currently, 130 nm is forecast for 2002 and 100 nm is forecast for 2005. However, in view of the tendency for acceleration each year, it is estimated that 130 nm and 100 nm will be realized in 2001 and 2003 respectively.

OUTLINE OF THE INSPECTION SYSTEMS

A Total Inspection/Yield Enhancement System

Inspection/evaluation systems operated in semiconductor process lines are divided into (1) In-line inspection, (2) On-line defect analysis and process evaluation, and (3) Critical dimension-measurement in lithography. Hitachi provides inspection equipment suitable for each inspection requirement. In addition, Hitachi proposes a total system which allows centralized control and management of data made available from each inspection equipment and/or system.

In this chapter, we report on in-line inspection including:

(1) A wafer inspection system which detects pattern defects and particles.
(2) A review system which reviews the detected defects and classifies them.
(3) An yield enhancement system which manages the inspection results and displays their relations with yield.
(4) An inspection system which is composed of analytical equipment and analyzes possible causes of poor yield.

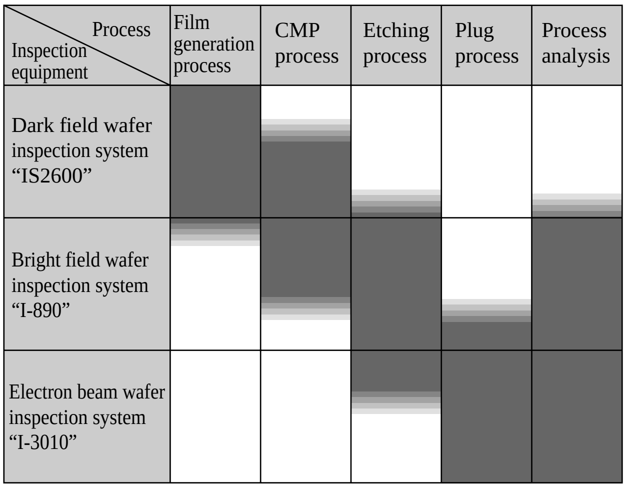
Wafer Inspection System

There are 3 models of wafer inspection systems made by Hitachi (Fig. 3).

(1) The I-890 optical wafer inspection system detects pattern defects and particles. It has a bright field optical system and is useful for etching processes or defect analysis.

(2) The IS2600 laser wafer inspection system detects particles on wafers of small steps at high sensitivity and high throughput. It has a dark field optical system.

(3) The I-3010 electron beam wafer inspection system detects very small defects which are difficult



Inspection equipment \ Process	Film generation process	CMP process	Etching process	Plug process	Process analysis
Dark field wafer inspection system "IS2600"	■	▨	▨		▨
Bright field wafer inspection system "I-890"	▨	▨	■	▨	■
Electron beam wafer inspection system "I-3010"			▨	■	■

CMP: chemical-mechanical polishing

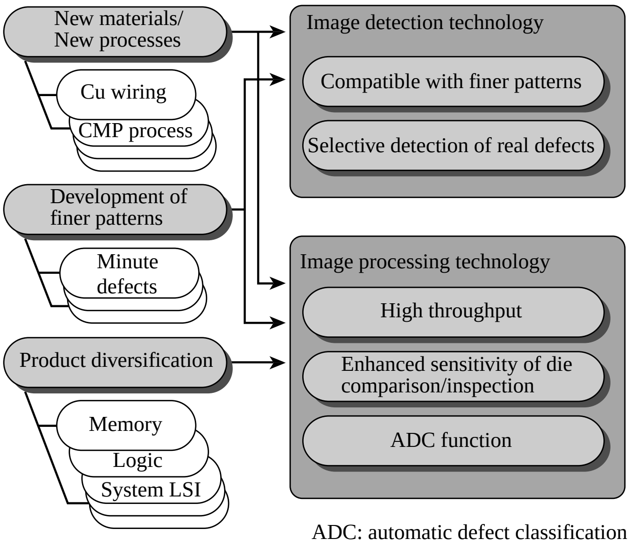
Fig. 3— Types and Functions of Wafer Inspection System Manufactured by Hitachi.
Utilization of the features of each inspection equipment and efficient adaptation to each process and defects for detection enables construction of an investment-efficient inspection system.

to detect with optical systems and also non-conductive defects in via-plug-process using a voltage contrast image.

We will explain the details of these wafer inspection systems as follows.

The I-890 Bright Field Wafer Inspection System

Associated with the development of new devices, new techniques compatible with the following requirements, which have never been requested, are demanded by the users (Fig. 4).



ADC: automatic defect classification

Fig. 4— Concept of Wafer Inspection System.
Devices respond to issues of new materials, new processes, finer patterns and product diversification through effective combination of image detection technology and image processing technology.

New problems generated by new materials or new processes

Planarizing processes using CMP or Cu damascene and multi-layer wiring, for example, will be used much more commonly in the future. With copper wiring, metal grains and with the planarizing process, color variations which can cause inspection problems will be a serious problem. It is necessary for the inspection equipment and systems to eliminate these false-defects in order to detect true defects only.

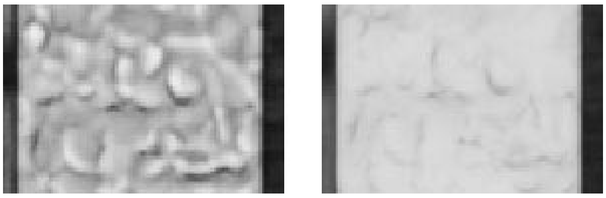
The I-890 optical wafer inspection system has an optical modification which is a hardware. Without the use of software, it eliminates parameters which interrupt proper inspection and thus provides a technique of true defect detection. This hardware technology is advantageous since it does not require complicated parameter setting as a software does. It operates with a simple recipe and runs quickly without dropping the inspection time due to processing steps of software solution.

The I-890 has an image detection technology which is grain compatible and is useful for wiring process. It allows detection of defects at a high sensitivity using an image contrast control. Users can lower the contrast by one fourth of normal mode (Fig. 5).

Problems with higher integration and density devices

When semiconductor devices move toward higher integration and density, high resolving power and high sensitivity for detection of small defects are required for inspection systems. For improving resolution and sensitivity, shorter wavelength and smaller image pixels are generally studied. The shorter wavelength is not just a change of the source. It is necessary to study effect of color variations with insulation layers. In this respect, removal of parameters that drop sensitivity is more extensively studied. For the I-890, a broad-band illumination, one of Hitachi's own technology, has been employed.

Smaller pixel size is an important development. Neither image resolution nor sensitivity can, however, be improved by small pixels. A hardware, which eliminates fluctuations and noise components from acquired images, is required, to avoid an increase of false-defects generated from the noise components.



(a) Ordinary detection image (b) Grain-compatible detection image

Fig. 5— Ordinary Detection Image and Grain-compatible Detection Image.
The "I-890" applies image detection technology to reduce grain contrast and selectively detect real defects with high sensitivity through hardware processing.

For achieving high resolution and high sensitivity, the I-890 has a hardware which eliminates noise components in the acquired images. At higher sensitivity, number of defects that can be detected will be great. These defects need to be reviewed efficiently and classified so that an effective use of ADC will be important.

The I-890 has a cell and die parallel processing function for comparison and performs inspection of system LSIs at a high sensitivity. This is another original technology of Hitachi.

Problems with a large variety of devices

By cell comparison inspection for memory devices, we have achieved a high sensitivity. For system LSIs, which are expected to grow in the future, a high sensitivity die comparison inspection will be an important technology so that inspection of other than cells may be performed at a high sensitivity.

The IS2600 Dark Field Wafer Inspection System

Primary requirements for a laser wafer inspection system are (1) high sensitivity and high throughput, (2) high sensitivity for particle detection from repeated pattern and mirror finished samples, and (3) high sensitivity detection of particles on oxide layers.

High sensitivity and high throughput are complementary. In this system, a parallel detector design using multi-channel sensors has allowed a high sensitivity and a high throughput without compromise. Laser wafer inspection systems in general have a problem of poor particle detection and sensitivity for patterned wafers compared to mirror finished wafers. Technologies for improving the sensitivity for both wafers often conflict among themselves. We have employed a special optical design for the IS2600 and have achieved a high sensitivity for repeated pattern wafers.

Oxide layers cause fluctuations of detector signals generated from substrates due to interference of thickness variations. These fluctuations are often detected as false-defects. For correcting these problems, it is necessary to lower the sensitivity which automatically lowers true defect detection sensitivity. To overcome this we have developed a unique algorithm for the detector which can cope with fluctuations of oxide layer thicknesses and can also maintain a very high sensitivity.

The I-3010 Electron Beam Wafer Inspection System

As semiconductor devices move toward higher integration, density and multi-layer structures, small fatal defects, which are difficult to detect with optical inspection systems, increase. An electron beam wafer inspection system has been expected resolving these fatal defect problems. The I-3010 electron beam wafer inspection system features (1) defect detection of non-conductive via-plugs or short circuits using voltage contrast images, (2) high sensitivity defect inspection of 0.1 µm or smaller, (3) high speed inspection at 200 s/cm^2. The voltage contrast images are particularly useful for detecting defects at the initial setup of process operations.

The S-7840 and S-9200 Review SEMs

Since systems have been improved in their operating performance, a large amount of defect data are available after the inspection. Instead of review work using optical review systems, a new review work using SEM review systems has increased. For facilitating the review work, the S-7840 review SEM has been incorporated with (1) ADR (automatic defect review) and ADC (automatic defect classification), (2) data interface with various inspection equipment, (3) an interface which transfers review results with SEM images showing the defects to an advanced data analysis system, and (4) defect sampling function which allows selection of type of defects for reviewing. The S-9200 is a critical dimension SEM with a reputed high speed X/Y stage and high sample throughput. It is a plan-view review system for process lines. The S-7840 has a motorized 5-axis stage for sample-tilted reviewing. It allows accommodation of an X-ray spectrometer for elemental microanalysis of particles.

The MI-7000 Yield Enhancement System

For yield enhancement, it is effective to arrange inspections based on R & D data of devices and make use of statistical techniques. Inspections of more than necessary drop productivity leading to waste of labor and increase of cost. An adequate number of inspection (sampling) and a proper sensitivity for inspection are vital for mass production lines.

One of the great features of the MI-7000 is a trace report function which provides users with an report showing results of a large number of analyses collected from various inspection equipment and systems. The MI-7000 is a user-friendly automated system (Fig. 6).

With conventional yield enhancement systems, people used to work with a large volume of inspection data taken at each inspection stage in the process lines and spend a lot of time extracting a relation with the yield. The MI-7000 relieves people from such work and allows them to concentrate on probing causes of the poor yield. Fig. 7 shows a typical example of a report prepared using the trace report function. The horizontal axis shows a flow of process and the vertical axis, a number of production lots. The map shows the inspections at each process for each lot which is in progress. The wafer map allows to display the direct data sent from the inspection equipment, or the data after elimination of defects generated in the previous process using a radio button. It allows display of an exact location of problems for direct viewing. At a touch of a detail button, a location of the problem in correlation to a tester will be displayed. It calculates yield impact at each process automatically and displays the results.

Using the MI-7000 yield enhancement system leads an easy understanding of the current status of the process line. It is also possible to pinpoint suspected causes of poor yield based on numerous statistical data.

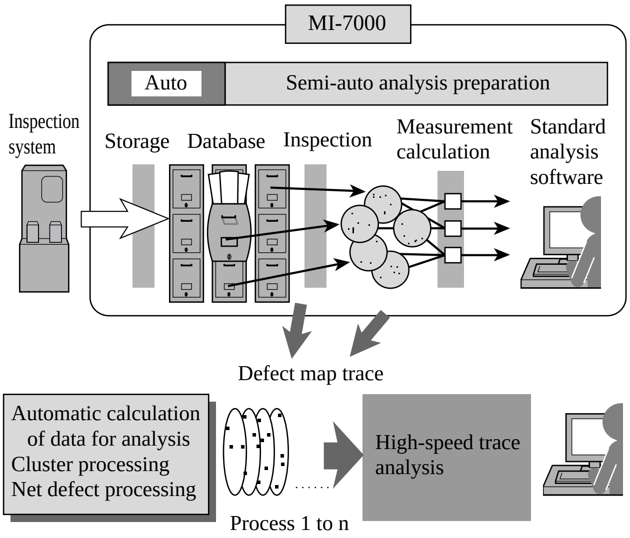


Fig. 6— Structure of Enhanced Data Analysis System.
Automatic performance of data pre-processing necessary for analysis allows speedy provision of analysis results.

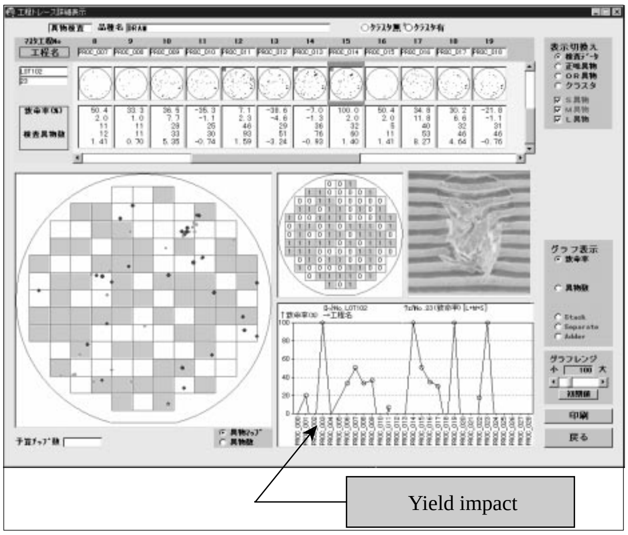


Fig. 7— Example of Report Prepared by MI-7000 Trace Report Function.
The screen not only displays a map table of the inspection results at each inspection process, but also a graph of yield impact data. Function facilitates identification of causes of reductions in yield.

Analysis Systems

In R & D of semiconductor devices, a high level of inspection and analysis techniques is required to finish the development within a short period of time. In order to increase the efficiency of a database of the results is ready for the R & D after a complete analysis of defect problems and thus anticipating the yield when such devices are processed in mass production.

For this type of analytical purposes, Hitachi offers the FB-2000A focused ion beam system, the HD-2000 ultra-thin film evaluation system, and high-resolution field emission SEMs.

For failure analysis of devices, a cross-sectional microscopy is a well known and useful technique. Hitachi’s FB-2000A and HD-2000 combination operates with the same specimen holder. This design allows specimen preparation and microscopy without repositioning the specimen. The combined system allows specimen preparation of a selected area of interest at a thickness of 0.1 µm or thinner and allows evaluation of subnanometer range. The S-4700 field emission SEM also operates in combination with the FB-2000A. Simple addition of X-ray spectrometer allows elemental micro-analysis of a specific area of interest after specimen milling using the FB-2000A.

TOWARD 0.1-µm PROCESS

We have reported current problems and various inspection systems. We believe that semiconductor industry will move toward further integration and higher density of devices of 0.1-µm processing. It is important for us to develop cost-effective inspection systems with development of (1) optical wafer inspection systems beyond the limit of optical resolving power, (2) higher throughput of electron beam wafer inspection systems, (3) efficient system design by taking advantage of each inspection system and using statistical processing of data made available at each process. Each inspection system will be required to challenge for limits of performance and the integration of each system needs to be studied for limits of yield enhancement.

For yield enhancement, for example, it will be necessary to make a correlation between defects and yield. For a close study of correlation, it will be required to classify all defects detected by inspection systems correctly considering possible effects on yield.

It is conceivable that the defect review and classification will be even more difficult when the number of detected defects increases as a result of higher integration and density of devices and improved performance of inspection systems. It will not be difficult to say that how to review and classify the defects efficiently, rapidly, and correctly will result in data which contribute to the yield enhancement.

It is, therefore, necessary to reduce the number of data efficiently in a flow of data processing through inspection systems from individual inspection equipment to data analysis system. One of the most important future assignments is to take advantage of various technologies associated with each inspection equipment, classify defects correctly, and process the data correctly and statistically (Fig. 8).

It has been pointed out that inspection systems in general are not quite compatible yet for the device processing of higher integration and density. We believe that it is quite important for us to proceed with consistent pursuit of technical possibilities in response to the above. Today, inspection systems have become a part of the semiconductor process equipment. The one who rules this approach rules the 0.1-µm process, we believe.

CONCLUSIONS

Here, we have reported on Hitachi's semiconductor inspection equipment and systems for yield

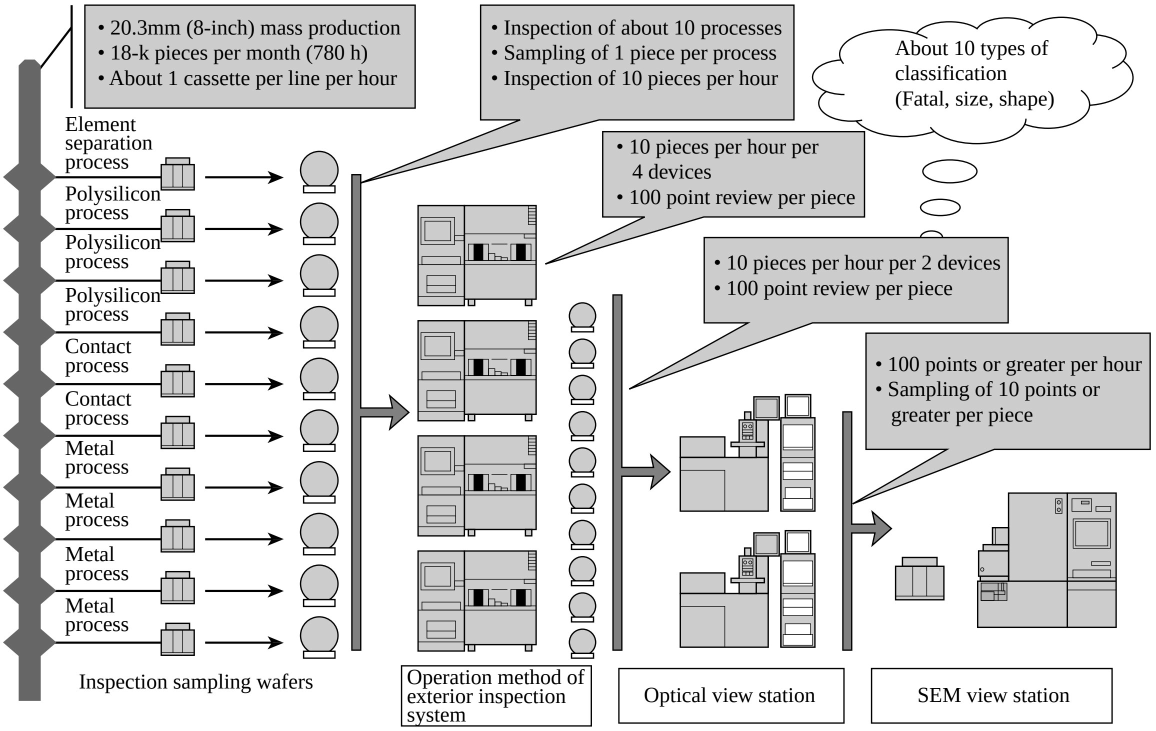


Fig. 8— Operation Method of Exterior Inspection System in Large-scale Mass Production Process.
At each stage of the inspection equipment, optical review equipment and SEM review equipment data sampling is carried out and classified information is obtained highly efficiently and effectively.

enhancement. We are prepared to continue challenging and developing new technologies toward 0.18-µm, 0.13-µm and 0.1-µm devices and propose new inspection systems accordingly.

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