Inspection System for High-Yield Production of VLSI Wafers

Toshimitsu Hamada[1], Jun Nakazato[2], Kenji Watanabe[3],
Fumio Mizuno[4], Shizuo Isogai[5]

[1] Nasu University, Faculty of Urban Economics
[2] Production Engineering Research Laboratory, Hitachi, Ltd.
[3] Semiconductor and Integrated Circuits Group, Hitachi, Ltd.
[4] Instruments Group, Hitachi, Ltd.
[5] Instruments Group, Hitachi, Ltd.

Abstract

It is believed that the majority of fatal failure in the semiconductor manufacturing process comes from foreign particles and appearance defects. Therefore, it is essential to achieve high-yield production to find them as soon as possible and to feedback inspection data to manufacturing process.

Failure analysis by using in-line inspections helps earlier process feedback. There are two types of in-line inspection tool; particle inspection and defect inspection. Particle inspection tool uses laser scattering method and inspects wafer surface at high speed. On the other hand, defect inspection tool uses image comparison method and inspects wafer surface at high sensitivity. It is important to use these two types properly in accordance with purposes. Defect inspection tools are used mainly in ramp-up production period, because wafers must be inspected at high sensitivity to detect new types of defects which occur in new process. In mass production period the configuration of inspection tools is optimized to inspect many wafers at high speed and inspect wafer in critical process at high sensitivity. The way to analyze inspection data depends on purpose, and there are a lot of ways to analyze data which are developed based upon know-how or experiences. Moreover these inspection tools bring too enormous inspection data for human to analyze.

We have developed total inspection system that consists of a lot of inspection tools for detecting particles and defects, a lot of instrumental tools for reviewing and measuring them, and management system for gathering inspection data and analyzing them. The developed system provides earlier process feedback based upon in-line inspection which brings us high yield production.

1. Introduction

The development of semiconductor devices is very remarkable, and the generation of device alters every 3 years. So it is the key to the business success for the device maker to improve the yield rapidly during the development and trial period and to keep the yield high during mass production.

The pattern size of semiconductor devices proceeds from sub micron to quarter micron, and the diameter of wafer grows up from 200 mm to 300 mm. These circumstances decrease process margin and increase process failure. The foreign particles and defects which occur in manufacturing process cause more than 80 % of fatal errors of devices. So it is very useful to detect foreign particles and defects in manufacturing process as soon as possible and to feedback these data to manufacturing process.

The inspection tools have been making great progress with the development of semiconductor devices. The improved inspection tool can detect a lot of defects in short time, and many inspection tools are applied in many manufacturing processes. These inspection tools brings on enormous inspection data. It is important to analyze these data and identify problem. However inspection data is too enormous for human to analyze. We have developed analysis system in which inspection data are gathered automatically and data analysis is made interactively.

2. Inspection in semiconductor manufacturing

2.1 Failure analysis on semiconductor wafer

There are three methods in failure analysis on semiconductor wafer; 1) failure analysis on probe testing data, 2) physical analysis using optical microscope, SEM(Scanning Electron Microscope) or FIB(Focused

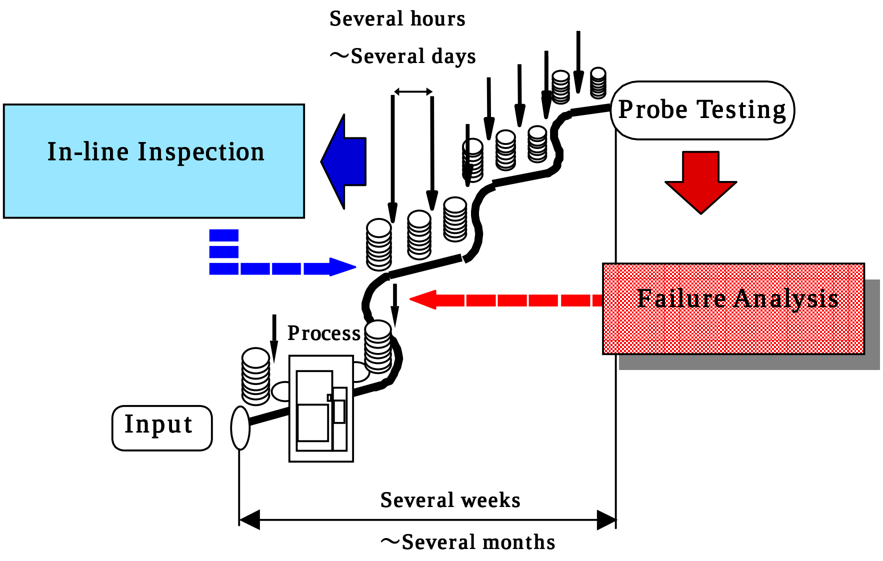


Fig.1 In-line Inspection and Failure Analysis

Ion Beam) equipment, and 3) failure analysis based upon in-line inspection data which are gathered in particle/defect inspection tools or measuring tools.

In failure analysis on probe testing data, we identify defective process or equipment by analyzing testing data which are got in several test programs based upon device design data or processing data. However it takes a lot of time from input of wafer to getting probe testing data in the final process as shown in Fig.1.

Physical analysis is getting more difficult with development of device especially on positioning the observation point of wafer. It takes a lot of time in physical analysis because of the difficulty.

On the other hand, the number and kind of defects detected in in-line inspection is less than in probe testing. However particles, defects and changes of process parameter which cause the majority of fatal errors can be detected in in-line inspection. And improvement of defective process or equipment can be carried out in earlier manufacturing process by analyzing in-line inspection data than by failure analysis on probe testing data or physical analysis as shown in Fig.1.

Therefore there are a lot of in-line inspection and measuring tools. For example particle inspection tools are applied in deposition process, and particle and defect inspection tools and measuring tools are applied in lithography process and etching process. Inspection and measurement data are analyzed to identify defective process or equipment, and are transferred to reviewing tools and analyzing tools for physical analysis if necessary. Moreover in-line inspection data are compared with the result of failure analysis on probe testing data to determine fatality of particle or defect detected in in-line inspection.

Above-mentioned failure analysis based upon in-line inspection data grows more important because a lot of inspection tools are applied. This analysis needs a lot of know-how, and it was done by human formerly. However improved and new inspection tools bring too enormous data for human to analyze. So needs of analysis support system increase.

2.2 Purpose of inspection in production period

In semiconductor manufacturing the purpose and content of inspection changes according to production period (shown in Fig.2).

(1) Development and trial period

Novel manufacturing processes or novel materials are often applied to develop new devices. A lot of kinds of particles and defects might be brought by these novel technologies. So in this period wafer must be inspected with high sensitivity to detect as many particles and defects as possible. And these inspection data must be analyzed to judge whether particles or defects bring fatal error of device. In this period comparison of in-line inspection data with probe testing data, identifying manufacturing process in which there are a lot of particles or defects, and so on are often done. Moreover physical analysis is often applied by using inspection data.

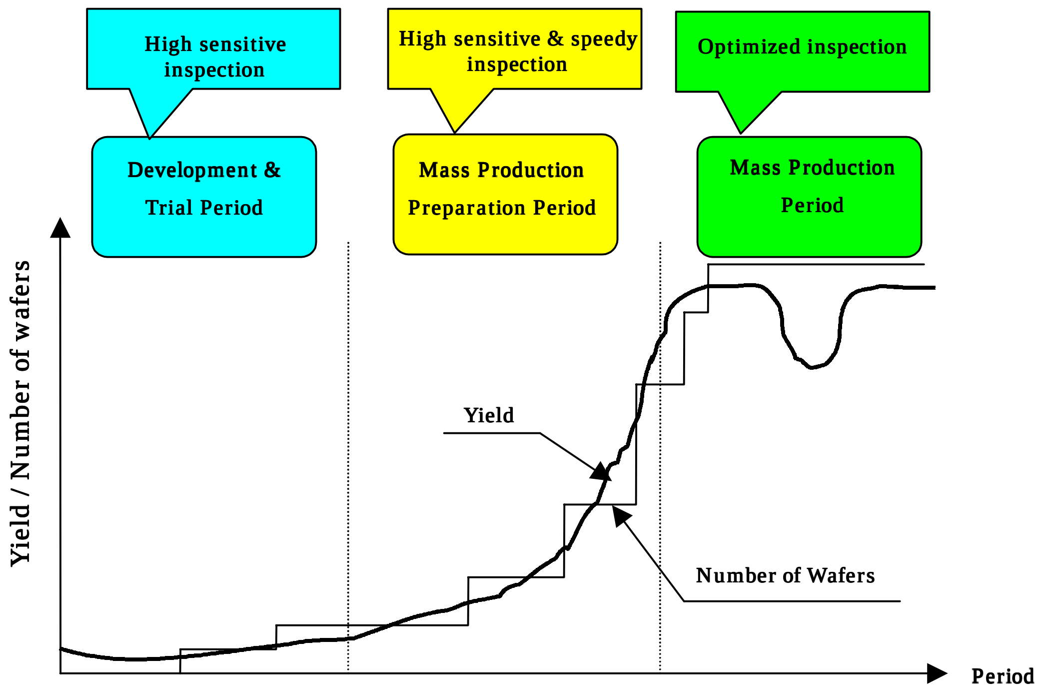


Fig.2 Inspection and Production Period

(2) Mass production preparation period

In this period high speedy in-line inspection with high sensitivity are demanded to achieve rapid yield ramp-up and keep steady manufacturing. And the number of inspection tools grows up according to increase of manufactured wafers. In addition to analysis in development and trial period, monitoring the process by using inspection data is done to confirm effect of improvement.

(3) Mass production period

In this period it is important to detect sudden occurrence of particles or defects which bring fatal error. In order to cope with these situations the number and kind of inspection tools are optimized according to manufacturing process and the number of manufactured wafers. Moreover the frequency on inspection, that is the number of inspected wafers, is optimized too. Analysis by monitoring is mainly applied in this period.

3. Inspection system

3.1 Inspection tool

There are various types of in-line inspection tool. This paper fixes its view upon particle inspection and defect inspection. These inspection tools can detect various types of particles and defects which might occur in manufacturing process, but it is necessary to tune up tools in order to keep high performance. And it is necessary to choose process in which the inspection tool can do the best performance, too. The principles and features of these tools are shown in Fig.3.

(1) Particle inspection

Particle inspection tool uses laser scattering method. In this method laser light is illuminated on wafer surface in oblique direction, and scattered light on surface is gathered. Particles are detected based on the difference between intensity of scattered light on particle and good wafer surface. In this method high resolution imaging is not necessary, so this type of tool can inspects wafer surface at high speed. The throughput of particle inspection tool is 1－2 min/200 mm wafer which corresponds to the throughput of semiconductor manufacturing equipment. The sensitivity of inspection is about 0.3 μm. The price of this type of tool is comparatively low, and a lot of tools are used in a lot of manufacturing processes.

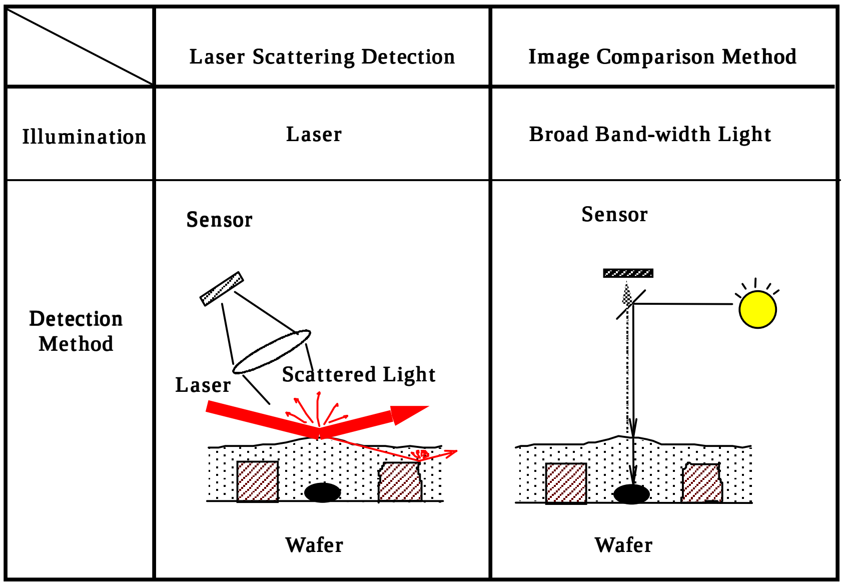


Fig.3 Principle of Inspection

(2) Defect inspection

Defect inspection tool uses image comparison method. In this method broad band-width light is illuminated on wafer and image sensor detects image of wafer surface. Defects are detected by image processing of die-to-die comparison or cell-to-cell comparison. This type of inspection tool inspects wafer surface at high sensitivity. In order to realize high sensitivity defect inspection tool adopts high resolution imaging, and inspection sensitivity depends on pixel size of imaging. Therefore it takes more time to inspect wafer by using this tool than particle inspection tool, and the price of this type of tool is comparatively expensive. The throughput of defect inspection equipment is several 10 min/200 mm wafer, but the sensitivity of inspection is about 0.1 μm.

3.2 Analysis system

These inspection data must be analyzed to improve the manufacturing process and enhance the yield. The inspection data are too enormous for human to analyze, and various types of data which include not only in-line inspection data but also probe testing data must be analyzed systematically to identify defective process or equipment. The developed system is described as follows.

(1) System configuration

The configuration of the developed system is shown in Fig.4. Analysis system is constituted of server workstation and client PC. All inspection tools are connected via LAN, and inspection data are transferred

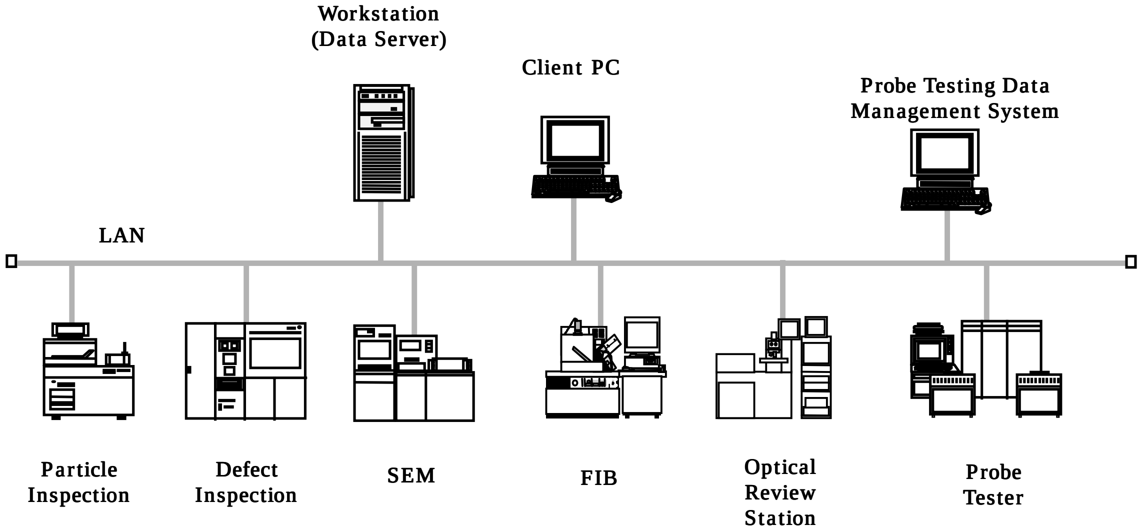
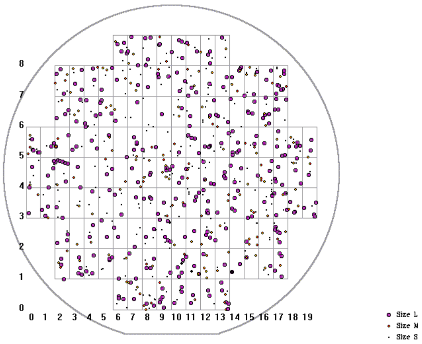


Fig.4 System Configuration

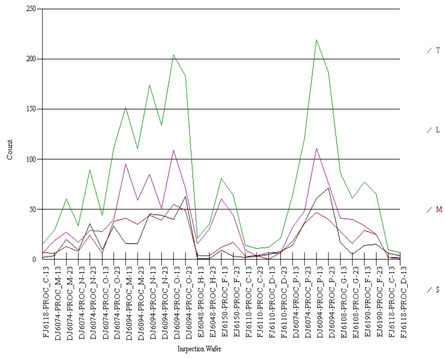
Table 1 Analysis Functions

Analysis	Functions
Particle Analysis	Distribution map, Density map, Overlapping map, Transition chart, Process trace (Adder particle analysis), Histogram, etc.
Defect analysis	Distribution map, Density map, Overlapping map, Transition graph, Process trace (Adder defect analysis), Histogram, etc.
Testing Data Analysis	Fail category map, Transition chart, Overlapping map, Histogram, etc.
Correlation Analysis	Correlation scatter diagram, Correlation ratio chart, etc.
Image Data Management	Storage, Search, Display, etc.

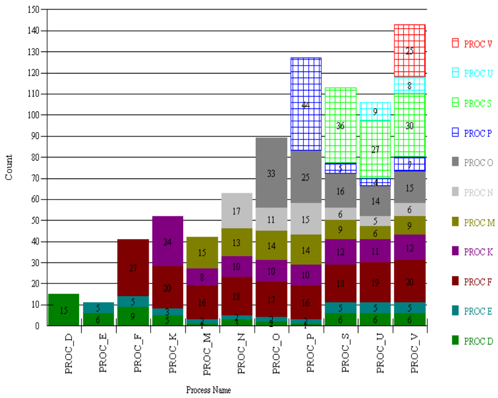
to analysis system. Transferred inspection data are stored in the database in the workstation. Moreover review stations are connected via LAN. Inspection data in the database are transferred to review station, for example SEM, FIB or optical reviewing tool, in which detailed observation of particles or defects is done by using particle or defect position data . Image data obtained in review station are transferred to workstation, and are stored in the database, where image data are related to inspection data. Further probe testing system is connected together via LAN. Probe testing data can be transferred to workstation, and are stored in the database as well. Data in the database are transferred to client PC in accordance with analysis request. This systematic configuration realizes effective and powerful analysis on in-line inspection data.



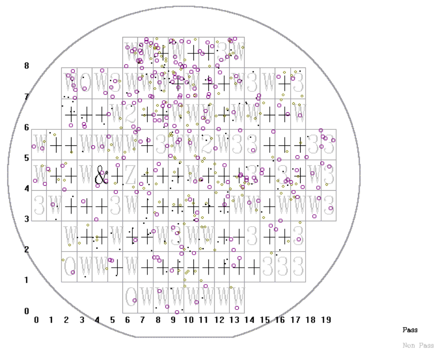
(a) Distribution Map of Particles



(b) Transition of Particles



(c) Adder Particle Analysis



(d) Overlapping Map of Defects and Probe Testing Data

Fig.5 Examples of Analysis Results

(2) Analysis function

Main analysis functions of developed system are shown in Table 1. There are basically five kinds of analysis: defect, particle, and testing data analysis, correlation analysis, and image data management. In the first three analyses not only each data but also other data, that is particle data and defect data, are processed. These processing are useful for identifying defective process or equipment. In correlation analysis contribution to yield of particles or defects are analyzed statistically. This analysis is useful for determining the control level of particles or defects. These processing are done in client PC, and other processing can be easily added if necessary.

4. Examples of analysis

Examples which are analyzed in the developed system are shown in Fig.5. Fig.5 (a) shows particle map. Total map with enlarged map in specified die is also available. Fig.5 (b) shows transition of the number of particles in specified process. This analysis indicates the quality of process roughly. Detected particles in inspection tool contain not adder particles generated in the present process but also adherent particles generated in the previous process. More detailed analysis is shown in Fig.5 (c). In this analysis adder particles are separated by inspecting the same wafer in each process. This analysis enables us to determine the process generating the largest number of particles, which might be the defective process. Fig.5 (d) shows comparison between defects and probe testing data. This analysis enables us to determine defect which influences yield.

5. Conclusion

Inspection system for high-yield production of VLSI wafers has been developed. In the system inspection tools are connected via LAN, and inspection data are transferred to analysis system. This system configuration enables various functions in analysis system, and helps physical analysis in the review station. The system realizes effective failure analysis using in-line inspection data, and contributes improving yield and keeping high yield.

Reference

[1] Kenji Watanabe, et al.: "Defect control on CMP process and high throughput inspection technique" , SEMI Technology Symposium 98 , pp. 7-94~7-100 (1998/12)

[2] T. Mugibayashi, et al.: "A novel quantitative analysis of defects detected by in-line monitoring", The Seventh International Symposium on Semiconductor Manufacturing (ISSM’98), pp.335-338, (1998)

[3] Kazunori Nemoto, et al.: “A New Systematic Yield Ramp Methodology” , ASMC’99, pp.21-24 (1999)

[4] Makoto Ono, et al.: "Non-defective Area Analysis for Quantifying Yield Impact", The eighth International Symposium on Semiconductor Manufacturing (ISSM ‘99) , pp.127-130(1999)