Introduction of Reticle/Mask Particle Detection Integrated System

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PD is an instrument to detect particles on Reticle/Mask used in the semiconductor exposure process. A new product PD Xpadion, which is an integrated PD series to one platform, was released in 2021. It is designed for easy customization and to meet a wide variety of requests in the semiconductor market. This article will introduce features and new functions of PD Xpadion.

Introduction

PD is mainly used for process quality control of the exposure processes in semiconductor factories and for in-process and pre-shipment inspections in mask production at mask shops. In recent years, PDs have also begun to be used for quality control of production processes for leading-edge EUV lithography, with more than 370 units in operation worldwide to date.

Demands for analyzers in the semiconductor market continue to change because of factory automation, SEMI standards, and technological progress to achieve higher integration and functionality in conjunction with very complex patterns. The requirements are becoming more diverse and complex every year, and it has become difficult to meet all requirements with the conventional PD series platform.

Through nearly 40 years of supplying particle inspection systems to the reticle/mask market, HORIBA has developed an understanding of the requirements of customers for analyzers and the know-how for the development and design of automatic inspection systems (Figure 1).

In order to respond quickly to market demands, we have organized these achievements and integrated the previous PD series functions into a single platform, the new PD Xpadion.

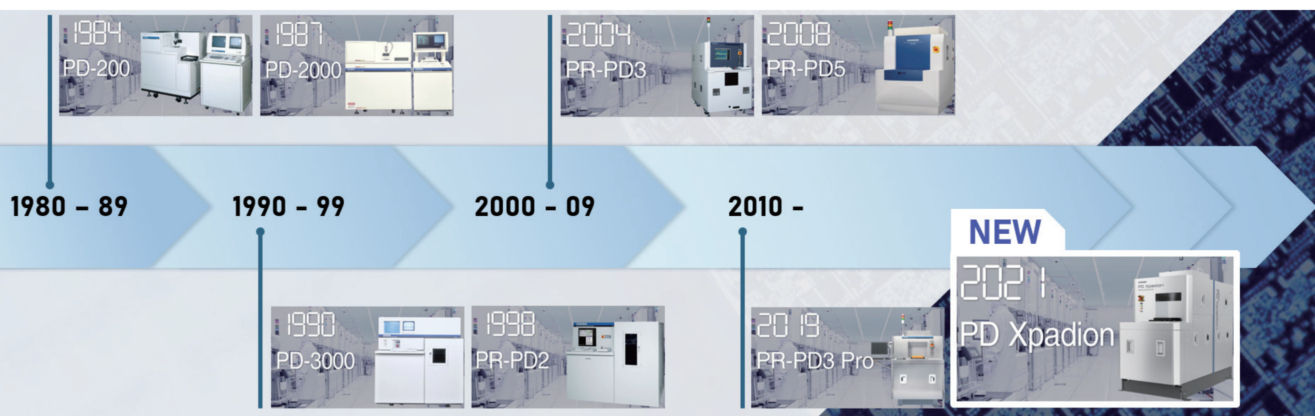

Figure 1 History of PD series.

Principle of PD measurement

The basic principle of particle detection in PD is to irradiate a laser beam onto a reticle/mask (hereinafter referred to as “reticle”) and detect the scattered light.

The entire surface of the reticle can be inspected by scanning a laser beam using a galvano scanner and moving the stage simultaneously. In addition, by implementing the inspection optics above and below the inspection target, high-speed inspection of the pattern surface, pellicle surface, and glass surface is possible (Figure 2).

As for the optical system for particle detection, a standard optical system for patterned reticle applications, a multi-detector optical system, and a high-sensitivity detection optical system for blank mask applications are available, which are selected according to the corresponding application (Table 1).

Standard optical system

Detection optics designed for patterned reticles with detection sensitivity down to 0.35 μm. False detections can occur when diffracted and scattered light by the pattern is unintentionally detected as a particle. In this optical system, the optical arrangement of the detector and the polarization component of the measured light are controlled to reduce false detection signals as well as maintaining the sensitivity of the scattered light that is dependent on the particles.

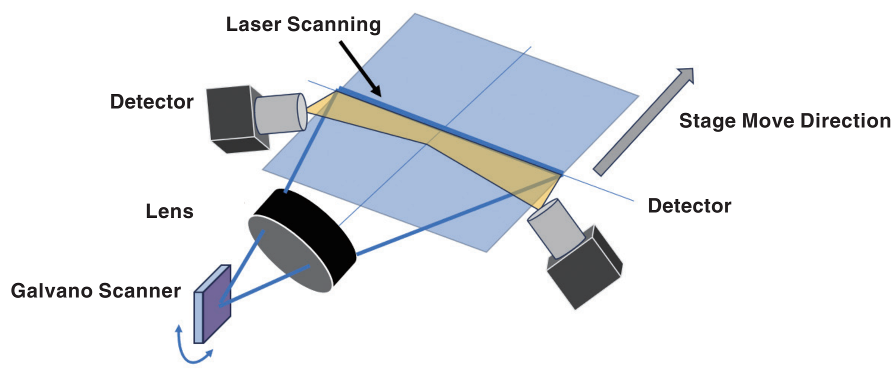

Figure 2 Structure of optical system.

Table 1 Optical system option list.

	Standard optical system	Multi-detector optical system	High-sensitivity detection optical system
Optical implementation			
Feature	—	Reduction of false detections	High sensitivity
Inspection target	Patterned reticle		Blanks mask

Multi-detector optical system

False detections from patterns that emit strong diffracted and scattered light in a specific direction, such as circular patterns, have been a problem. The multi-detector optical system solves this problem. By implementing another pair of detectors at specific positions in the system, one of the detectors can avoid diffraction scattered light. False detections can now be significantly reduced for reticles such as power semiconductor interconnections and hole patterns for surface wiring, which have been unsatisfactory in the past.

High-sensitivity detection optical system

Since the blank mask has no pattern formed on its surface, there is no need to avoid diffracted scattered light from the patterned reticle. By employing an all-light focusing optical system that actively detects scattered light generated by particles, high-sensitivity inspection down to a particle size of 0.1μm is achieved.

Features of the new PD Xpadion

PD Xpadion is a product characterized by flexible customizability through combinations and high usability. Detailed features are described below.

Feature 1: Flexible customizability

PD is used for various applications, such as pre-shipment inspection by reticle manufacturers and routine inspection by semiconductor device manufacturers prior to exposure. The equipment configuration is changed according to the application, such as detection sensitivity and reticle size to suit the customer's use. In the conventional PD series, the range of customization in product models was limited, however, the PD Xpadion offers a wider range of options that can be combined as a unit, enabling rapid customization.

A typical example of customization is the load port where samples are loaded. Reticles, which are used as base plates for semiconductor circuit production in the exposure process, are usually kept in specific cases or pods to prevent contamination by particles. PD Xpadion is compatible with cases made by various exposure equipment manufacturers and is also available with a variety of options for factory operations, such as multiple slots for placing several cases and linkage with OHT (Overhead Hoist Transport: an automatic transport system that holds sample cases and runs on track rails installed on the ceiling).

The optical system for particle detection depends on the use and application, such as patterned reticles and blank masks as explained earlier.

Many other options are also available, such as barcode and RFID code reading functions, 9-inch mask support, etc., allowing a wide range of customization to suit the customer's operations, not limited to specific combinations.

Feature 2: High usability

PD Xpadion provides various functions useful for improving the workflow of customers. Among them, we will explain the auto-size function for particle images and the simulation function for rank classification of particles-defects, both of which have had significant improvements.

- Auto-size function for particle images

  This is the function which observes particles detected by laser scattered light under a microscope and automatically measures the size of the particle by image processing. Although the principle of particle detection by laser scattering can determine the area where a particle emits light, the range is greatly affected by the shape and material of the particle and may not correspond to the actual size of the particles. In many cases, the actual size of the detected particle is used to make a pass/fail judgment in production process particle control, and especially for large particles, the operator must manually observe the detected object to determine what to do. By automating the flow from inspection to observation by microscope and size measurement using this function, the operator's workload can be greatly reduced.

- Simulation function for rank classification of particles-defects
  The PD can be ranked into three categories (A<B<C) according to the size of the area where the detected particle emits light, and a pass/fail judgment can be made using the number of detected particle for each rank (Figure 3). For example, if 5 or more particles of the highest rank C are detected, the PD can set judgment conditions according to the customer's operation. As mentioned above, the emission range of detected particles by laser scattering varies depending on the shape and material of the particles, so with the conventional machine, it was necessary to optimize the parameters by repeatedly performing actual measurements while changing the threshold values. In the case of complex conditions, this process took more than half a day. PD Xpadion streamlines this task by using a function that simulates the state after a change in rank threshold from the result data. Recipe creation can be completed with only one measurement (Figure 4).

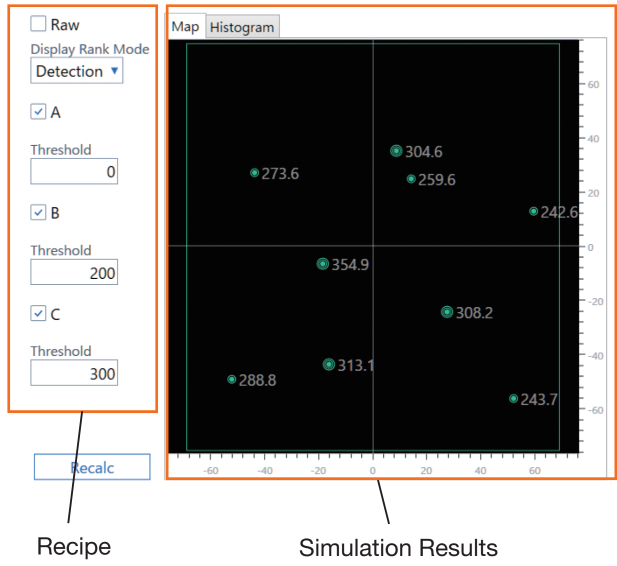

Figure 3 Software operation view.

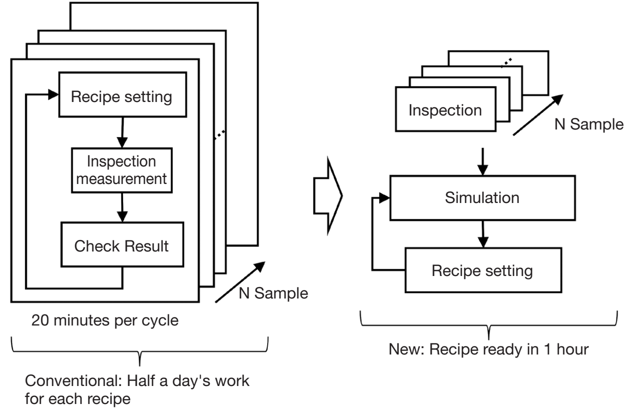

Figure 4 Comparison of optimization for recipe.

PD Xpadion EX System Introduction

PD Xpadion EX, a system product integrating a PD specialized for particle inspection and a reticle/mask transfer loader, was newly developed in 2024. The system can be connected to a transfer loader, allowing for a wider range of customization by enabling multiple load ports and linkage with other units, contributing to improved workflow by selecting the optimal specifications for each factory operation.

Multi load port

PD Xpadion EX allows multiple load ports to be expanded in various combinations of case types. When multiple different types of cases are used in a factory, conventional single-port equipment requires transferring to a specific case and setting it on the PD. The multi-load port reduces the risk of reticle contamination during transfer operations by combining load ports that correspond to multiple case types in operation.

The load port to be unloaded can be changed according to the results, for example, only reticles with a PD particle detection result of NG (more than a specific number of particle detected) can be segregated to a specific port.

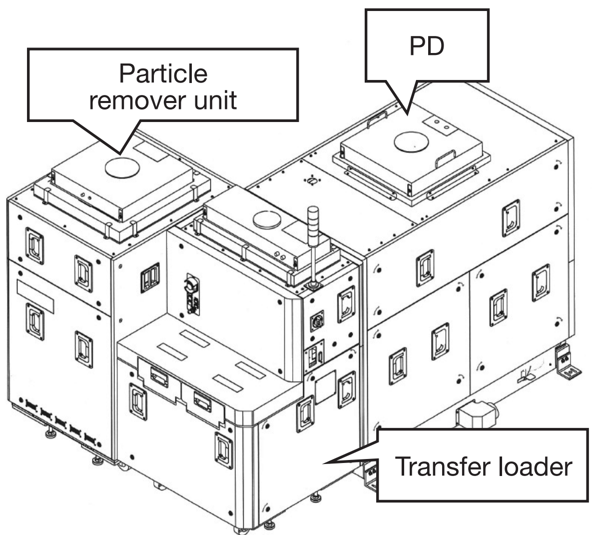

Figure 5 External view of the instrument.

Unit Integration

In unit integration, units other than the PD are connected to provide "+α" functions for particle detection. One of these functions is a particle removal unit. By connecting this unit, it is possible to automatically remove particle attached to the pellicle surface/glass surface of the reticle detected by the PD.

Clean dry air blown from the cleaner head, which locates the top and bottom from reticle surfaces, removes particles from the target surface, and then suction in the vicinity of the reticle effectively cleans the reticle. This not only streamlines the work by automating the conventional manual removal of particles by air blow, but also solves the problems of pellicle damage due to human error and particles re-attached to the reticle when the reticle is inserted or removed from the case.

Removal performance tests with 5 μm glass beads on the glass surface and 20 μm glass beads on the pellicle surface have confirmed removal performance of more than 90%.

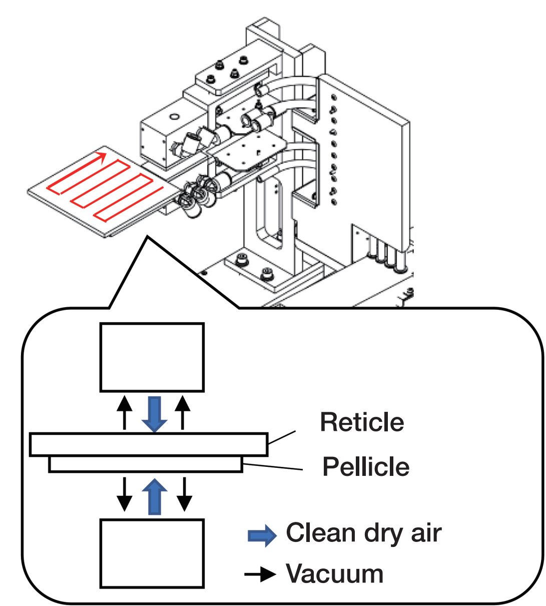

Figure 7 Mechanism to remove particles.

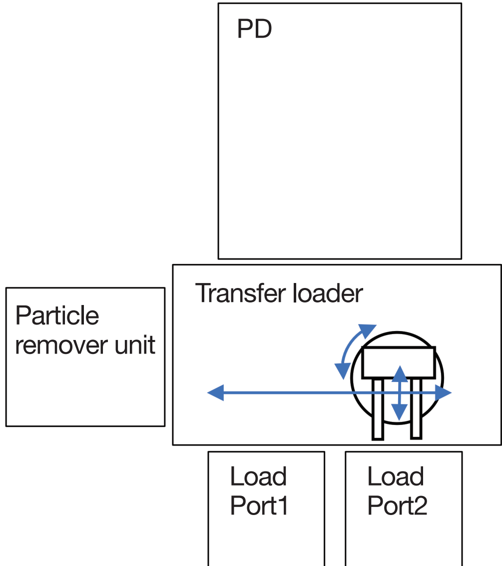

Figure 6 Structure of unit connection.

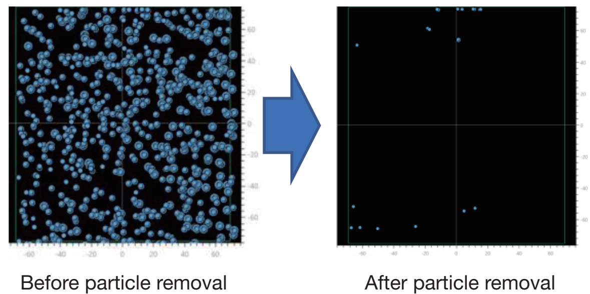

Figure 8 Particle removing result.

Conclusion

The PD Xpadion introduced this time is a product completed by integrating the know-how that HORIBA has accumulated over the years into a single PD platform. By efficiently incorporating the customization that has been handled in the past into the system design, a number of useful functions have been incorporated. In addition, the use of a new optical system has significantly reduced false positives, which had been a detection issue in the past.

PD Xpadion EX will provide new value to customers by building a system around the transport loader. In the future, the HORIBA Group plans to further develop applications by connecting various analyzers owned by the HORIBA Group, such as Raman spectroscopy, ellipsometers, and X-ray fluorescence analysis.

We have a wide range of applications that we can handle, and we hope to solve our customers' problems together with them using our new platform and the know-how we have cultivated over the years.

* Editorial note: This content is based on HORIBA's investigation at the year of issue unless otherwise stated.

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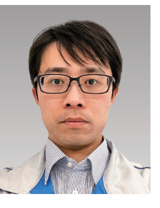

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