Featured Articles

An Inspection and Measurement Technology Platform Leading the Way to More Advanced Manufacturing

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OVERVIEW: The inspection and measurement of things is indispensable to manufacturing activities in order to guarantee that products are manufactured as designed. For inspection and measurement in the manufacturing industry, Hitachi's Research & Development Group has set forth an inspection and measurement technology platform consisting of four core technologies: (1) visual inspection and metrology, (2) nondestructive inspection, (3) chemical measurement and probe imaging, and (4) optical 3D shape measurement. The group for the technology platform is working on developing inspection and measurement technologies designed to handle a variety of objectives. By improving the four core technologies, the group will help improve the quality and ensure the reliability of Hitachi's manufacturing activities, and lead the growth of the inspection and measurement equipment business segment. To illustrate some examples of the development of these core technologies, this article describes technologies for visual inspection of semiconductor wafers, nondestructive inspection, using X-rays and supersonic waves, nano-resolution microscopy, bio-molecular measurement, and optical 3D shape measurement.

INTRODUCTION

NEEDLESS to say, the inspection and measurement of things is indispensable to manufacturing activities in order to guarantee that products are manufactured as designed. Although these activities are indispensable for quality assurance, the investment in plant equipment that is required for them tends to be underfunded because they do not contribute directly to production. In practice, outstanding inspection and measurement technologies are necessary for improving plant-wide productivity and quality. In addition to ensuring product quality and reliability, this platform also provides benefits such as reducing defects generated in manufacturing processes, and automating manufacturing processes by eliminating adjustment and setup work. The Internet of Things (IoT) has recently become a focus of media attention. The inspection and measurement technologies used with new manufacturing methods that make use of the IoT are core technologies that measure object states in real time and store them as digital data. Combining real-world data and various simulation technologies in virtual spaces is creating advances in mass customization enabling immediate manufacturing of products that are tailored to a wide variety of client needs.

Designed to help improve quality and ensure reliability for Hitachi manufacturing and to lead the growth of the inspection and measurement equipment business segment, the Hitachi, Ltd. Research & Development Group's inspection and measurement technology platform for the manufacturing industry sets forth four core technologies: (1) visual inspection and metrology, (2) nondestructive inspection, (3) chemical measurement and probe imaging, and (4) optical three-dimensional (3D) shape measurement. The group for the technology platform is seeking to augment technology development in these core areas, which cover a wide array of product segments ranging from mechanical parts to materials and process products. It is working on developing high-precision external and internal defect detection technologies and advanced technologies to enable imaging and visualization of previously unseen states and phenomena.

This article describes the characteristic strengths of these core technologies, their use in Hitachi's manufacturing, and their application to inspection and measurement equipment.

VISUAL INSPECTION AND METROLOGY

Hitachi is developing visual inspection and metrology tools based on optical detection technology and image processing technology for detecting minute particles and defects in products.

Semiconductor Wafer Inspection

World-class inspection technologies are developed that enable high-speed, and highly-sensitive detection of defects on semiconductor wafers. The developed technologies are applied to Hitachi High-Technologies Corporation's visual inspection tool. They enable nanometer-scale defect control, helping improve the manufacturing yields and product reliability of device manufacturers.

Optical Detection Technology

A highly-sensitive optical defect detection system has been realized with a polarization control element that was developed using simulation with both a scattered light model of defects by laser emissions and vector beam propagation analysis[1]. The polarization control element converts radially polarized scattered light from a defect to linearly polarized light. And a polarizing filter selectively filters out scattered light from the wafer surface so as to enable stable detection of 18-nm size defects (see Fig. 1).

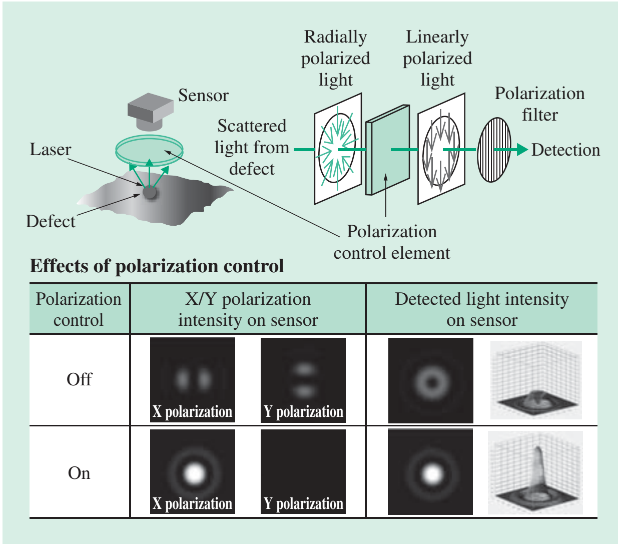

Fig. 1—Optical Defect Detection System.
Scattered light from defects (radially polarized light) is detected by converting it to linearly polarized light, increasing its discrimination factor relative to scattered light from the wafer surface, and enabling high-sensitivity detection.

Image Processing Technology

As semiconductor process design rules continue to shrink, the size of a defect becomes as much as the pattern variation derived from production tolerance. To solve this issue, advanced defect-detection algorithms are needed. Hitachi is working on creating more sensitive detection algorithms by combining conventional gray-scale-based image comparison methods with more advanced perturbation matching[2] and feature-based pixel comparison methods.

Scanning electron microscope (SEM) images are helpful for detailed defect observation. For improving defect visibility, Hitachi has developed image enhancement algorithms[3] including a noise reduction and image resolution enhancement based on an optical system detection model (see Fig. 2).

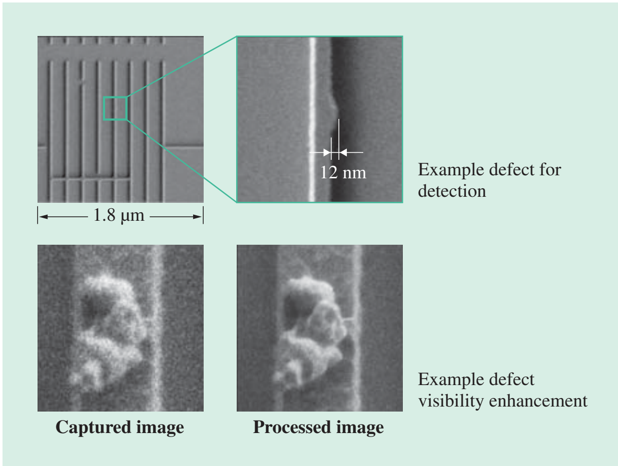

Fig. 2—Image Processing for Defect Inspection.
Hitachi is developing image processing algorithms for minute defect detection/visibility enhancement.

NONDESTRUCTIVE INSPECTION

Hitachi is developing non-destructive inspection technologies for visualizing the inside of a product using X-rays and supersonic waves. The developed technologies are used in Hitachi's industrial high-energy X-ray computed tomography (CT) scanners, and in Hitachi Power Solutions Co., Ltd.'s ES Series of ultrasonic testing systems. They contribute to efficiency, and improvement of manufacturing process and product quality.

Industrial High-energy X-ray CT

The conventional (second-generation) method required translation and rotation operations for one cross-sectional image. To enable rapid imaging without decreasing the detection accuracy, Hitachi has developed a new (third-generation) method that can create an image using only rotation operations, by densely arranging thin semiconductor sensors as detecting elements. The new method achieves high-speed imaging at a maximum speed of ten seconds per cross-section(4).

A detector array with between 500 and 1,000 elements per row is placed in opposition to an X-ray source. Using a collimator that is aligned with a high degree of accuracy, only the X-rays from the specific direction are incident on each element, thereby preventing cross-talk between elements and enabling both high-speed imaging and highly accurate detection (see Fig. 3).

Ultrasonic Inspection Technology

Hitachi developed inspection technology that uses two ultrasonic waves with orthogonal vibration axes(5). In the conventional method, it was difficult to identify defect signals because of reflection noise generated at the crystal interface, and only defects of the order of several millimeters could be detected. Using two ultrasonic elements that send and receive ultrasonic waves having orthogonal vibration axes, it is now possible to acquire the signal of each axis individually. For example, in rolled steel, two ultrasonic waves having orthogonal vibration axes have different propagation speeds. So, the defect signal of each wave appears in a different position. Based on the difference in propagation speed, a method to correct the defect signal position was developed. As a result, the signal-to-noise ratio (S/N) improved, and defect detection on the order of sub-millimeters was achieved (see Fig. 4). In future, this method will be commercialized for use in the receiving inspection of procurement materials.

CHEMICAL MEASUREMENT AND PROBE IMAGING

Hitachi's research centers are leading the way in the development of technologies for detecting high-resolution optical images that could not be seen previously, and for measuring molecular functions. The goals of these technologies are applications such as quality control for cutting-edge devices, and medical diagnoses using disease-linked bio-molecules.

Nano-resolution Microscope

Hitachi is developing a probe-type microscope that enables nano-resolution measurement of physical properties and composition states. It is designed for applications such as quality assurance of cutting-edge devices and inline inspection during manufacture. A nano-sized spot of light is generated at the tip of

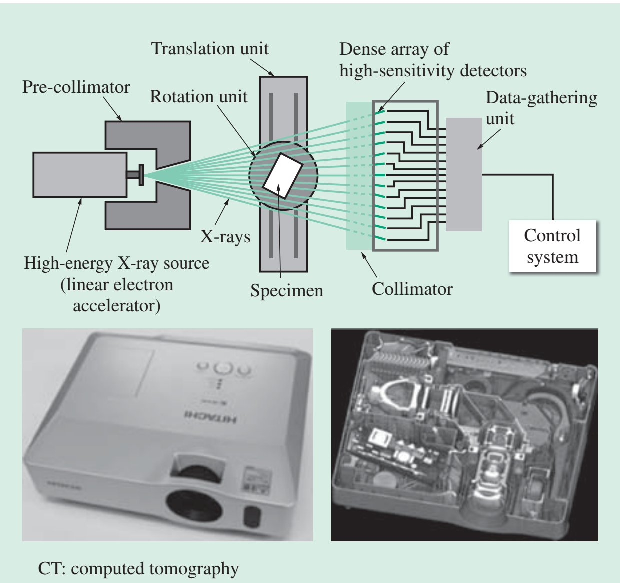

Fig. 3—Industrial High-energy X-ray CT Scanner Configuration and Internal Imaging Result.
The top diagram shows the configuration of an industrial high-energy X-ray CT scanner. The bottom-right image is the internal imaging result. The scanner achieves a 0.2-mm resolution using a dense array of high-sensitivity detectors and a collimator.

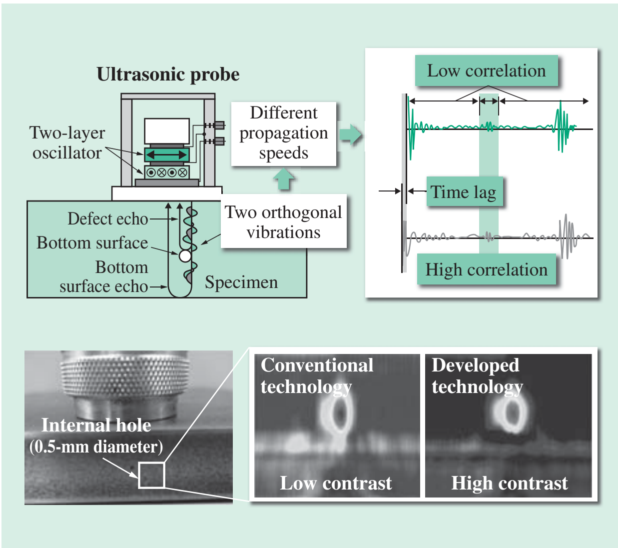

Fig. 4—Two-axis Ultrasonic Probe Configuration/Detection Waveform and Internal Imaging Result.
The top diagrams show the configuration and detected waveforms of a two-axis ultrasonic probe. The bottom-right images are the internal imaging results. Using the correlation between ultrasonic waves having two axes, the equipment can detect sub-millimeter-sized defects.

the probe, and scanned to enable the acquisition of a nano-resolution optical image that greatly exceeds the diffraction limit.

Fig. 5 is a schematic diagram of the developed detection probe. A plasmon waveguide composed of a gold film formed on a silicon cantilever tip converts incident light to surface plasmons that are efficiently coupled with a carbon nanotube (CNT) optical probe. As a result, near-field light of about 4 nm in diameter is generated at the CNT optical probe tip, and is used to enable imaging of a nano-resolution optical image on a sample. In addition to applications for characteristic analysis of devices and materials, this technology will ultimately lead to the development of nondestructive measurement tools for cells.

Bio-molecule Capture/High-sensitivity Measurement Using Molecularly Imprinted Polymers

Hitachi has developed molecularly imprinted polymer technology that enables advanced medical diagnosis through the measurement of disease-linked bio-molecules existing in trace concentrations (nmol/L) in biological samples[(6), (7)]. Molecularly imprinted polymer technology uses a target molecule as a template to create a polymer nearby. The surface of the polymer has holes shaped like the target molecule. By covering the surface of a core particle (made of polystyrene) with the molecular template polymer, the aim is to efficiently capture trace molecules to achieve high-sensitivity measurement (see Fig. 6).

OPTICAL 3D SHAPE MEASUREMENT

For high-efficiency production and the quality assurance of products, it is important to measure shapes during manufacture and to provide measurement results as feedback for the design, processing, and assembly processes. Hitachi is therefore working on developing laser-driven high-precision 3D shape measurement technology.

Hitachi has developed technology that enables contact-free, high-precision shape measurement using lasers, such as optical comb lasers with comb spectrum characteristics, as well as technology for processing/analyzing measured large-volume 3D point cloud data[(8), (9)]. It is working on developing technologies to support parts ranging from large machinery parts in equipment such as generators, compressors, and railway car bodies, to small parts with complex shapes such as automotive parts (see Fig. 7).

CONCLUSIONS

In addition to the technologies described in this article, the inspection and measurement technology platform also encompasses work on developing inspection and measurement technologies for various other objectives

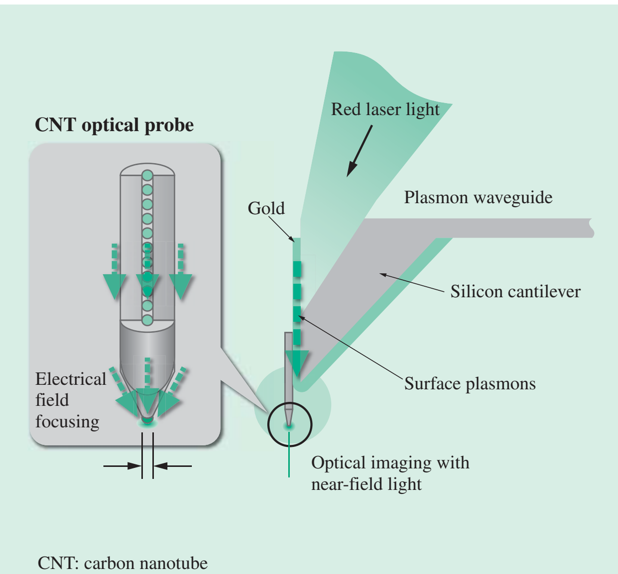

Fig. 5—Schematic Diagram of Developed Optical CNT Probe.
A plasmon waveguide generates near-field light at the tip of a gold-coated silicon cantilever. The light is scanned to enable acquisition of a nano-resolution optical image.

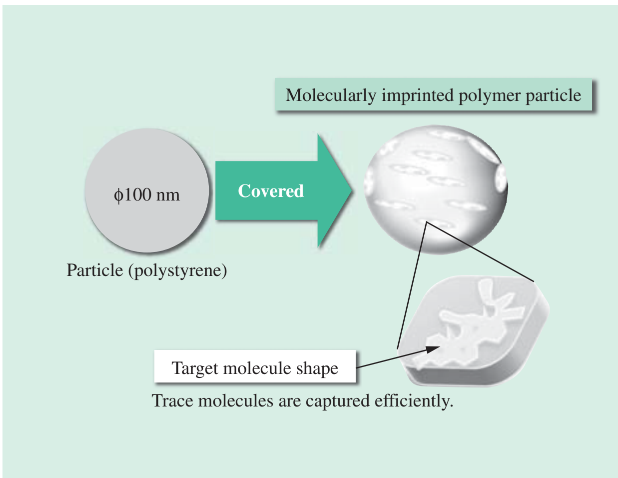

Fig. 6—Schematic Diagram of Molecularly Imprinted Polymer Particle Creation.
The surface of a polystyrene particle is covered with a molecularly imprinted polymer corresponding to the target molecule. This enables the high-sensitivity measurement of trace molecules by forming holes that efficiently capture the target molecule.

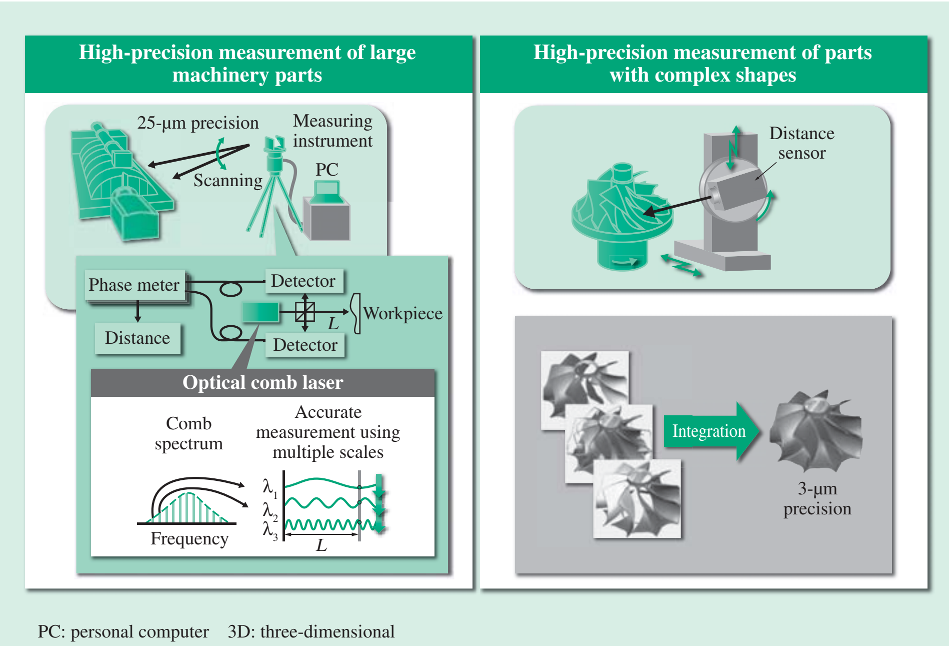

Fig. 7—High-precision 3D Measurement Technology.
Hitachi has developed technology for contact-free, high-precision measurement of shapes ranging from large machinery parts in equipment such as generators and compressors, to small parts with complex shapes such as automotive parts.

and methods. This work will assist the inspection and measurement activities of Hitachi's manufacturing, and lead the growth of Hitachi's inspection and measurement equipment business segment.

Moreover, advances in IoT-based manufacturing will result in increasing use of digital data enabled by advanced inspection and measurement technologies, continuing to help make Hitachi manufacturing more advanced.

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