DUV Optical Wafer Inspection System for 65-nm Technology Node

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OVERVIEW: The trend of miniaturization in advanced semiconductor devices is accelerating. Against this background, the performance required of a wafer inspection system extends beyond simply greater sensitivity to include accommodating new materials such as ArF photoresist, Cu wiring, and low-k materials as well as higher throughput for 300-mm wafer production lines. With the aim of developing a system that meets the requirements outlined above, Hitachi-High Technologies Corporation began joint development of the high-performance DUV (deep ultraviolet) optical wafer inspection system with TOKYO SEIMITSU Co., Ltd. in 2003. That system is now on the market. By employing DUV light, which has a shorter wavelength than the conventionally used white light and UV (ultraviolet) light, as the light source, this system makes use of the more intense illumination to attain a smaller inspection pixel size and higher detection sensitivity. It furthermore achieves a throughput that is several times higher than that of conventional systems by employing one of the world's fastest image processing devices. This system is thus able to cope with nodes of 65 nm and smaller.

INTRODUCTION

AS the trend of miniaturization of advanced semiconductor devices shows no signs of abating, some advanced device manufacturers are proceeding from the 90-nm development process node to 65-nm technology; the mass production process node, too, is shifting from 100 nm to 90 nm and below. For these leading-edge devices, fine processing technology with ArF exposure that makes free use of OPC (optical proximity correction) and the use of new materials that include high-*k* materials such as the gate insulation layer, low-*k* materials used between wiring layers, Cu, strained Si, and SOI (Si on insulator) is accelerating. As such new technology is being introduced, wafer inspection systems are confronting problems such as fine defects that cannot be detected by conventional

RDC: real-time defect classification
SEMI: Semiconductor Equipment and Materials Institute
GEM: generic equipment model
FA: factory automation

For next-generation processes	90- to 65-nm nodes
Inspection modes	Cell-to-cell mode Die-to-die mode Cell/die hybrid mode
Fast inspection	Three wafers per hour (ø 300 mm)
Automatic defect classification	RDC standards SEMI/S2-0200
Accords with safety standards	CE-MARK
FA	GEM (option)

Fig. 1—DUV Optical Wafer Inspection System.
This is the most advanced DUV optical wafer inspection system. We achieved high sensitivity and high throughput for 90-nm node and below for process development and for mass production.

equipment and the detection of new defect modes that accompany use of new materials. Market demands on optical wafer inspection systems include those listed below.

(1) The high sensitivity required for detection of fine defects

(2) Pattern noise reduction and SN (signal-to-noise) ratio improvement

(3) Incorporation of an automatic defect classification function

(4) Achievement of both high sensitivity and high throughput inspection

To meet such needs, Hitachi High-Technologies Corporation and TOKYO SEIMITSU Co., Ltd. have collaborated in the development of the high-performance DUV optical wafer inspection system, which we describe in the following section.

FEATURES OF NEW DUV OPTICAL WAFER INSPECTION SYSTEM

Highly Sensitive Defect Detection

Highly sensitive defect detection is achieved by using an optics that combines a DUV laser light source for high sensitivity with SR (super resolution) technology together with a high-performance die comparison algorithm.

Pattern Noise Reduction

The detection of pattern wafer defects involves the problem of detecting nuisance defects produced by color variations or grain. The system is capable of reducing such pattern noise by using a die comparison algorithm that tolerates differences in brightness.

Achieving High Throughput

To cope with the burgeoning amount of image processing that results as inspection pixel size becomes smaller and wafer size increases, we have achieved throughput several times that of conventional systems by the development of one of the world's fastest image processing devices and a high-speed comparison algorithm.

SYSTEM CONFIGURATION

Optics

Generally, the limit on optics resolution is proportional to the wavelength of the illuminating light, λ, and is expressed approximately using the numerical aperture of the lens as $\lambda/2NA$; shorter wavelengths allow higher resolution. A 266-nm wavelength DUV laser is employed as a high-output laser that produces a stable, continuous oscillation. Using the laser eliminates the effects of chromatic aberration, thus realizing extremely low aberration and wide field of view in this high-performance DUV objective lens. Furthermore, because there is abundant optical power, even for fast image scanning, this system can be applied under various detection conditions, including pixel size and the SR conditions described below, ensuring superior process adaptability. Speckle noise from use of the laser light source is eliminated by development of a low-coherence optics (see Figs. 2 and 4).

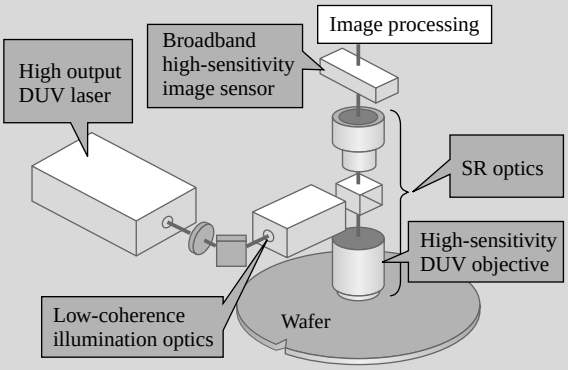

Fig. 2—DUV Optics.
Highly sensitive defect detection is achieved with optics that employ a 266 nm wavelength DUV laser, an illumination system that removes the speckle noise that is peculiar to the laser, and the SR optics, which has been highly evaluated in the SR system.

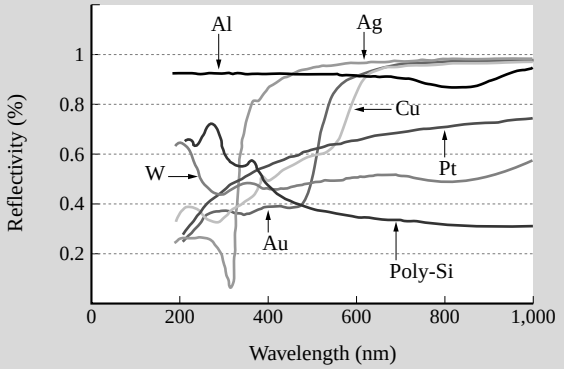

Fig. 3—Material Reflectivity Versus Wavelength (Spectral Reflectivity).
At wavelengths near 266 nm, both Cu and Al and have greatly different reflectivities than does Poly-Si, which is optimum for detection of wiring patterns because contrast with the background is easily obtained.

There is growing need for the detection of short defects in the Cu damascene process, which is becoming the mainstream wiring process. Light that has a wavelength of 266 nm has minimal reflectivity with respect to copper, and so has the advantage of allowing contrast with the background (see Fig. 3).

In addition to the high-sensitivity DUV optics described above, a newly developed high-sensitivity image sensor and die comparison algorithm allow detection of fine differences between dies, thus achieving sensitivity that is sufficient to detect small defects on the order of a fraction of the wavelength. Furthermore, we intend to improve sensitivity by using our proprietary SR optics (see Fig. 5) to sharply increase pattern contrast to near the limit of resolution. The SR conditions can be selected to be optimum for the process, thus providing a high degree of process adaptability.

Stage

To take advantage of the resolution obtained by the optics, we developed a new very fast and highly accurate linear motor stage with laser interferometers on the X and Y axes as well as a new highly sensitive broadband image sensor that features very fast and accurate real-time automatic focusing.

Image Processing

We developed a new high-speed, programmable image processing system for flexibility and to strengthen compatibility with various processes. This system is equipped with a die-to-die algorithm that smooths out process induced color variations and is capable of distinguishing fine differences in shape. Furthermore, a hybrid cell/die comparison algorithm that allows simultaneous comparison of repeated-pattern cell regions and random-pattern peripheral circuits to increase sensitivity for cells in die comparison.

A new RDC (real-time defect classification) function has also been added. This function uses differences in attributes to classify nuisance defects, which are detected as defects but do not directly affect device yield, separately from actual defects, removes them, and then reports the final detection results in real time. The system is equipped with this RDC as a standard function, which lightens the load on the operator and review system by automatically classifying nuisance defects and other defects, thus greatly reducing the number of defects that must be dealt with.

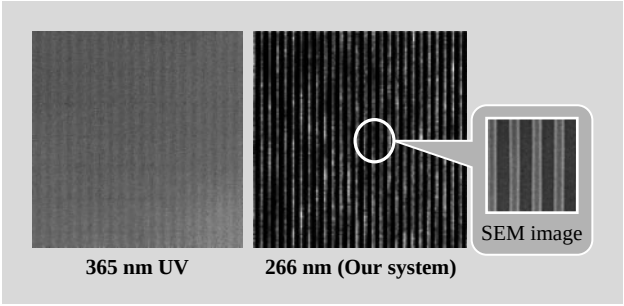

Fig. 4—Effect of Reduced Wavelength.
The microscale samples (0.11-μm line, 0.13-μm space) produced by Hitachi High-Technologies Corporation are clearly resolved.

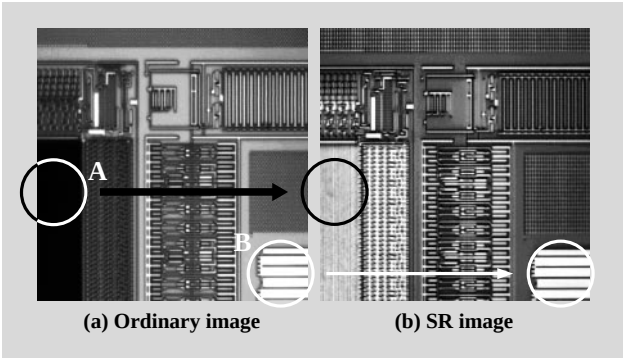

Fig. 5—Effect of SR Optics.
The SR improves the contrast of the fine pattern part A to near the limit of resolution, and the signal from the sparsely patterned, highly reflective part B is controlled.

APPLICATION EXAMPLES

Fine Defect Detection Capability

As shown in Fig. 4, the use of short-wavelength illuminating light achieves a striking improvement in resolution compared to conventional systems that employ white light or UV light. This greatly improves the capability for fine defect detection in fine patterns as shown in Fig. 6. The data presented in the figure are the results for only the actual defects in the device (from the left: our system, other DUV inspection system, UV broadband inspection system). For 90-nm node devices, our system detected from two to four times as many defects as did the other system. The good results versus the other DUV system comes from our system's use of intense laser illumination, which allows a smaller detection pixel size than does lamp illumination.

Furthermore, our system was able to detect 10 times as many defects than the other system for the even finer 70-nm node devices. We expect this system to

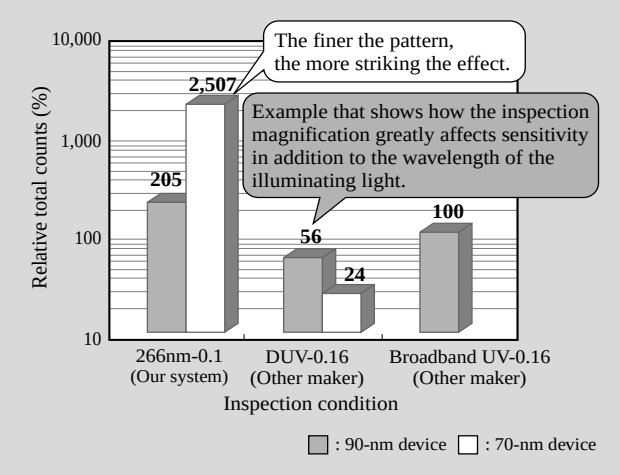

Fig. 6—Fine Defect Detection Capability of Our System. Superior results are attained relative to the lamp-sourced DUV inspection system of another company as well as compared to broadband UV illumination. The effectiveness for 70-nm technology is even more conspicuous.

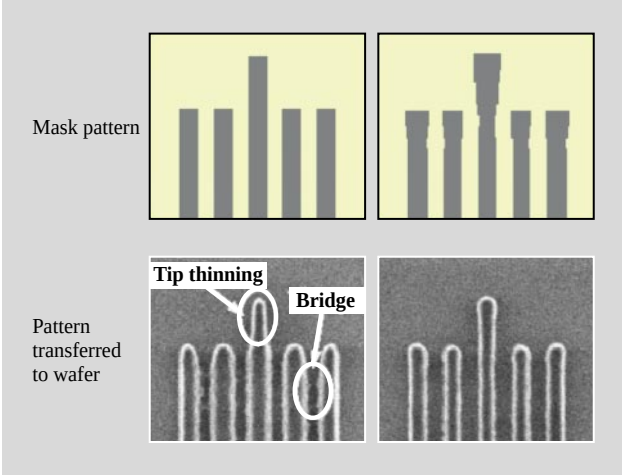

Fig. 7—Examples of Effect of OPC Correction. With an uncorrected mask, the proximity effect prevents transfer of the desired pattern. To correct for that effect, various corrective patterns are formed on top of the mask.

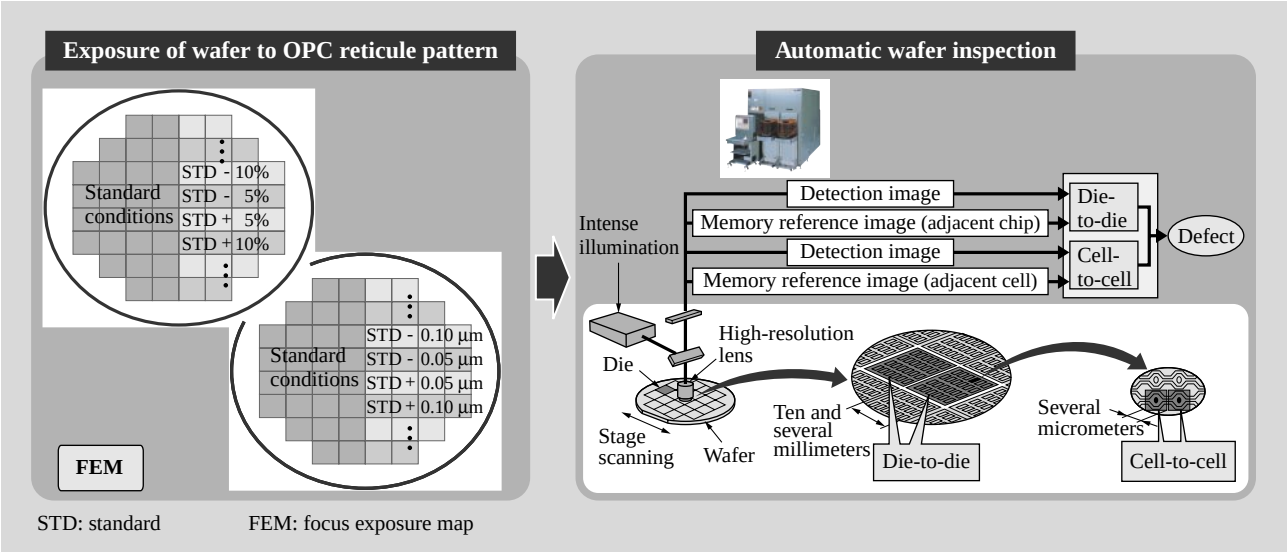

Fig. 8—OPC Reticule Evaluation Method. The OPC reticule pattern is transferred to the wafer under various exposure conditions. The transferred pattern is inspected with the wafer inspection system in die-to-die mode.

be even more effective in the development and production of the later 65-nm node devices.

Application to Reticule Evaluation

For the exposure of 65-nm node devices and other such fine patterns, the desired pattern processing cannot be done without using an ArF light source and a reticule that has been corrected for various proximity effects. An example of the effect of OPC is shown in Fig. 7. Because this kind of correction is done, the exposure margin is smaller than with the conventional method, thus making it difficult to maintain a stable, high yield in mass production. The exposure margin is determined with a pragmatic approach in which the actual exposure is done with amount of exposure and the focus as parameters, the pattern is transferred, and the transferred pattern is examined. Evaluation of all of the patterns over the entire mask would take a very long time, so various efficient methods are being sought[1]. Of those, the use of a wafer inspection system to detect and evaluate defects that arise according to changes in exposure conditions is an effective method.

Above all, because our system uses an illumination light that has a wavelength that is close to the ArF exposure wavelength, greater contrast between the photoresist pattern and the background anti-reflection film can be obtained than is possible with conventional wafer inspections systems, making high-sensitivity inspection. The evaluation method is shown in Fig. 8.

The OPC reticule pattern is transferred to the wafer under various exposure conditions. At that time, the wafer inspection system is in the die-to-die mode, so both of the dies that are being inspected must have patterns that were exposed under standard conditions. Attention must be given to this point when preparing a sample wafer. In addition, defects that arise from changes in exposure conditions are highly likely to be found in the same locations in the die, so they appear as repeating defects from one die to another. An efficient inspection method would then be to extract only the repeating defects that occur at the same coordinate positions. Then, the defects detected by the wafer inspection system can be observed by SEM to determine the exposure efficiently. Hereafter proceeding to finer and finer dimensions, we believe that OPC reticule evaluation will become an important application of wafer inspection.

CONCLUSIONS

We have described our high-performance DUV optical wafer inspection system. Looking to the 90-nm node era and beyond that to 65-nm node era, inspection technology will be playing more and more important roles in expediting the development of advanced devices and production factory startup. In future work, too, we intend to strive for higher performance to respond to the requirements that come with finer patterns, new materials and higher speeds.

REFERENCE

(1) Hyunjo Yang et al., "OPC Accuracy and Process Window Verification Methodology for Sub-100 nm Nodes," SPIE (2004).

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