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PATTERNED WAFER DEFECTS INSPECTION BY LASER SCATTERING IMAGE

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Abstract: A new optical measurement method for detecting the semiconductor pattern defects, which does not depend on the physical limit of optical image formation, is presented. The experimental system consists of the Fourier transform optical system using of a high-power objective. In order to verify the feasibility of application of our proposed method to next-generation patterned wafer inspection technique, several primary experiments were carried out. It is shown that the proposed method is effective for detecting the small particle contaminants on the semiconductor circuits.
Keywords: Patterned Wafer Inspection, Laser Applied Measurement, Laser Scattering Image.

1 INTRODUCTION

In modern semiconductor technology, it is commonly known that defects such as particle contaminants will continue to be a major limiting factor for yield in semiconductors. Semiconductor manufacturers use yield management and process monitoring systems [1-3] to improve yields by identifying defects, by analyzing them to determine process problems. As feature sizes of semiconductor circuits continue to be small for leading edge semiconductor products, yields become more sensitive to the size and density of defects. In addition, the conventional optical inspection method for defects based on the optical image formation ultimately will reach physical limits imposed by the wavelength of light. Therefore the purpose of this study is to develop a new optical measurement method which is not based on the optical image formation but can be applied on the next-generation feature sizes with the linewidths of 0.25 μm and furthermore the smaller linewidths of 0.18 μm (256 Mbit DRAM).

2 INSPECTION BY LASER SCATTERING IMAGE

Figure 1 shows a schematic diagram of the principle of our proposed measurement method for detecting semiconductor pattern defects. It consists of the Fourier transform optical system using of a high-power objective (with the numerical aperture of 0.95). A converged beam by an objective has a beam waist in the focal length of the objective. Then the laser beam is incident on a patterned silicon wafer surface, which is placed at some distance (defocal length) away from the focal point of the objective. We have scattered light from the features of semiconductor circuits with defects as well as reflected light from a surface. By detecting the intensity distribution, "laser scattering image," corresponding to the superposition of the scattered light and the reflected light, we can evaluate the semiconductor pattern defects. This measurement method is not based on the optical image formation but on the scattering and the interference phenomena, which are not affected by physical limits imposed by the wavelength of light. Then the irradiance distribution of the laser scattering image is expected to be sensitive to the small features such as the next-generation linewidths.

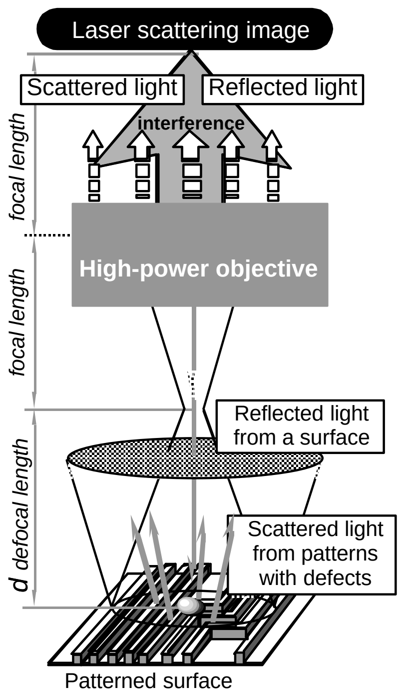

Figure 1. Principle of measurement

Figure 2 shows a concept of patterned wafer defects inspection based on the laser scattering

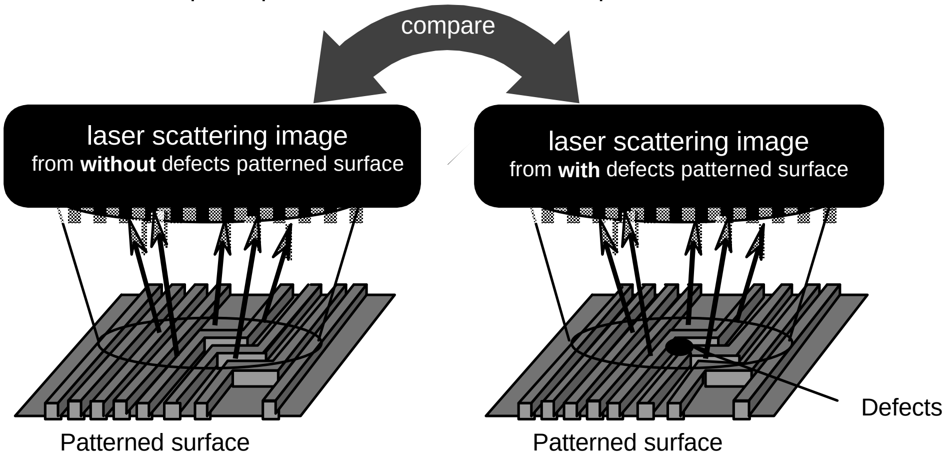

Figure 2. Concept of patterned wafer defects inspection based on laser scattering image

image. If laser scattering image is effected by the small defects on the patterned surface, defects can be identified by comparing its laser scattering image with that from non-defective patterned surface as shown in figure 2. The goal of this paper is to verify the feasibility of our proposed method by carrying out several primary experiments for estimating the basic properties of laser scattering image.

3 EXPERIMENTAL TECHNIQUES

Schematic experimental arrangement [4, 5] employed in this investigation is shown in figure 3. To prevent particle contaminants of the test surface, the optical system is housed inside a clean enclosure of class 10. An Argon ion laser of wavelength 488.0nm is used as the light source. After passing through the single-mode optical fiber (mode field diameter = 4.0 μm), the beam is collimated and polarized. Using a high-power objective (with the numerical aperture of 0.95), the incident beam is converged on the surface of silicon wafer. The silicon wafer is fixed to a computer controlled XY-fine positioning unit with stepping motor for moving and scanning the silicon wafer relative to the laser beam. The smallest possible step is given by 0.5 μm in both directions. The objective is mounted on the piezo actuator (allowing for absolute position control, high linearity and repeatability based on an integrated position feedback sensor) and can be moved over a range of 100 μm with a resolution of 10nm in axial direction). The beam power was monitored with a power meter at the position shown in

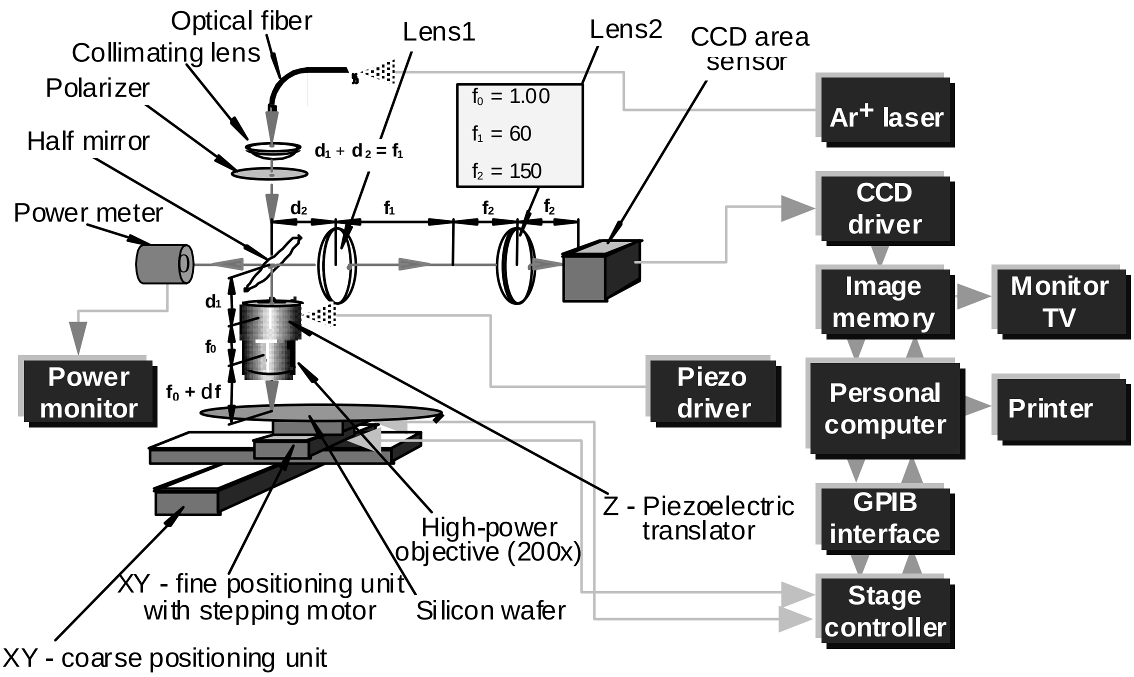

Figure 3. Schematic diagram of patterned wafer inspection system

figure 3, to which all detected data were normalized. A pair of lenses is used to observe the laser scattering image corresponding to a Fourier transform image of reflected light from the silicon wafer surface in the exit pupil of the objective. The irradiance distribution detected by the CCD area sensor consisting of 510 (H) x 492 (V) pixels and 12.9 µm (H) x 17.9 µm (V) pixels size is converged to 8bit digital image data and stored in the image memory. These data are dealt with by a personal computer with auxiliary memory.

4 EXPERIMENTAL RESULTS

First, in order to estimate the basic properties of this optical measurement method, primary experiments for detecting the laser scattering image of the standard sample were carried out. Second, in order to verify the feasibility of this method, we tried to detect a particulate contamination on the patterned surface by using the laser scattering image. In both experiments, test samples were identified by the use of SEM (Scanning Electron Microscope) after experiments.

4.1 Primary experiment for detecting laser scattering image

In order to verify that the laser scattering image is sensitive to the small features, we carried out an experiment for detecting the small particle contaminants, which can not be detected by the optical technologies based on the optical image formation. In this experiment, the standard polystyrene spheres with the diameter of 0.21 µm and 0.088 µm were deposited on the surface of bare silicon wafer. Their refractive index m = 1.59 approximates that of dust in the visible wavelength. The defocal length was adjusted to 5.0 µm and the spot diameter on the surface of silicon wafer was about 15 µm. Figure 4 and figure 5 show the experimental results of 0.21 µm particle and 0.088 µm particle, respectively. In these figures, figure (a) is a scanning electron micrograph, figure (b) shows the laser scattering image obtained in detecting the identical particle shown in figure (a). As shown in figure 4 and figure 5, the laser scattering images of the standard polystyrene spheres are seen to form concentric circle like an Airy disk. These effects may be caused by an interference effect of both light scattered by the particle and reflected from the surface of silicon wafer. From these results, it is clear that the laser scattering image is sensitive to the small features, which can not be detected by the optical technologies based on the optical image formation.

Next, in order to estimate the basic properties of laser scattering image obtained from a patterned surface, we carried out an experiment for detecting the laser scattering images of the standard line patterned wafer. Figure 6 and figure 7 are typical laser scattering images of standard line patterned wafer. Figure 6 and figure 7 show the result of 0.30 µm linewidths pattern and that of 0.27 µm linewidths pattern, respectively. The laser scattering images of patterned surface were detected as the stripe

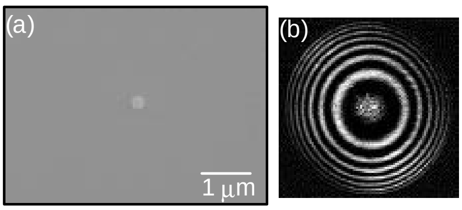

Figure 4. Detection result for 0.21 µm particle
(a) Scanning electron micrograph
(b) Laser scattering image

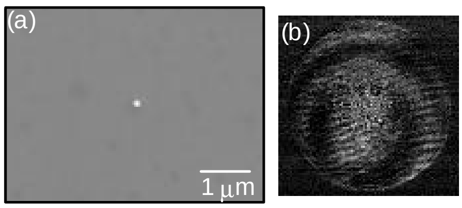

Figure 5. Detection result for 0.088 µm particle
(a) Scanning electron micrograph
(b) Laser scattering image

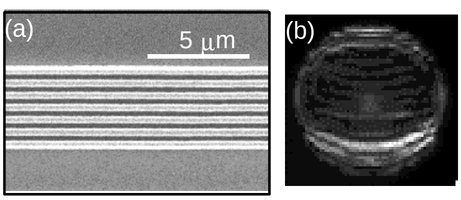

Figure 6. Detection result for 0.30 µm linewidths pattern
(a) Scanning electron micrograph
(b) Laser scattering image

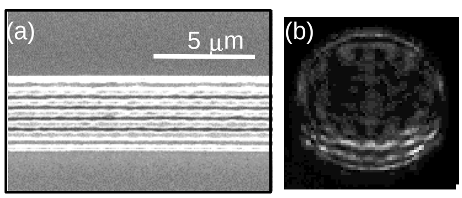

Figure 7. Detection result for 0.27 µm linewidths pattern
(a) Scanning electron micrograph
(b) Laser scattering image

4.2 Defect inspection based on laser scattering image

Since this experiment is primary one for detecting the pattern defects based on the laser scattering image, we used 0.30 µm linewidths pattern, which is suited for estimating the basic properties of our proposed method. In this experiment, we tried to detect a particle contaminant with the size of about 0.30 µm on the patterned wafer as shown in Figure 8 (a). The defocal length was adjusted to 3.0 µm. The spot diameter on the surface was about 10 µm. Figure 8 (b) shows the laser scattering image of the patterned surface with the particle contaminant. This laser scattering image was formed by the interference effect of both light scattered from the line patterns with the particle contaminant and reflected from the surface of silicon wafer. In order to investigate the effect of the scattered light from the particle contaminant, a scanning experiment was carried out. Figure 9 shows a procedure of this experiment. A beam spot on the surface of patterned wafer was scanned along the line patterns. The laser scattering images were detected at interval of 1.0 µm. We examined variation of laser scattering image by extracting a subtracting image from the next image. Figure 10 and figure 11 show the variations of laser scattering images about non-defective area and about the defective area, respectively. In both figures, images (A) are laser scattering images detected at interval of 1.0 µm, and images (B)

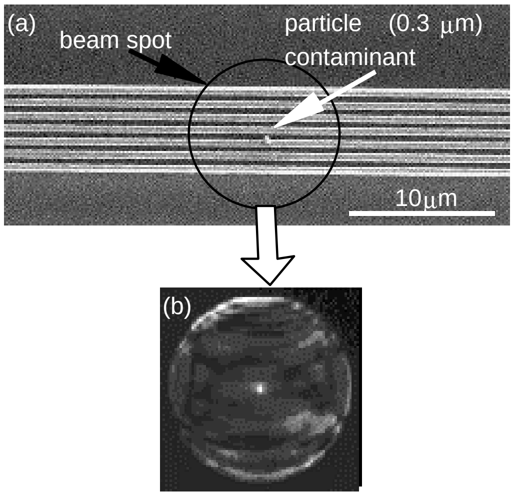

Figure 8. Laser scattering image of the defective patterned surface

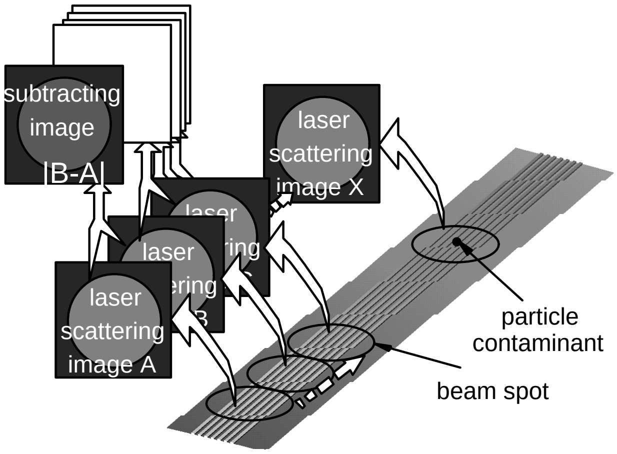

Figure 9. Procedure of a scanning experiment

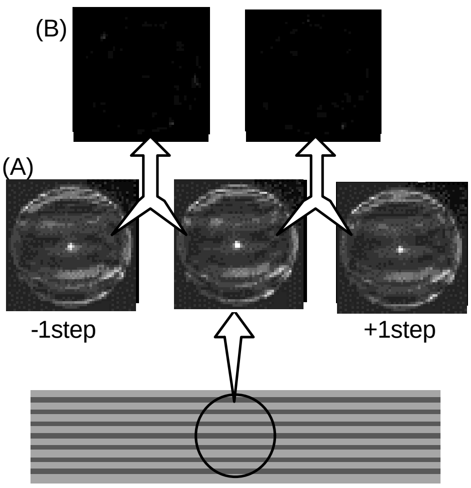

Figure 10. Variation of laser scattering image about non-defective area
(A) Laser scattering image
(B) Subtracting image

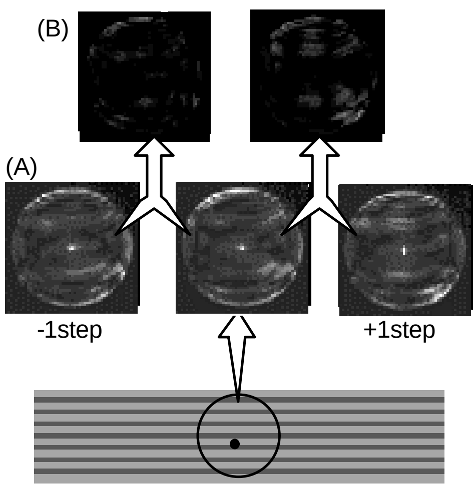

Figure 11. Variation of laser scattering about defective area
(A) Laser scattering
(B) Subtracting image

are subtracting images from the next images. Comparing figure 11 with figure 10, the subtracting images in figure 11 are brighter than those in figure 10 are. That means that the laser scattering images vary dramatically about the defective area. In other words, the laser scattering images are effected by the particle contaminant on the patterned surface.

Next, we tried to detect the position of the particle contaminant on the patterned surface by making the use of this variation of the laser scattering images. Figure 12 indicates the variations of brightnesses of the subtracting image. In this graph, the horizontal axis means the displacement of the beam spot from the position of the particle contaminant. The brightness of the subtracting image is steady about non-defective area and it rises to the peak about the defective area. This simple diagram seeks to capture the fact that the laser scattering images of the line patterns were strongly effected by the particle contaminant with the size of 0.30 μm. These results suggest that defects can be detected by comparing the laser scattering images between the patterned surfaces with and without defects.

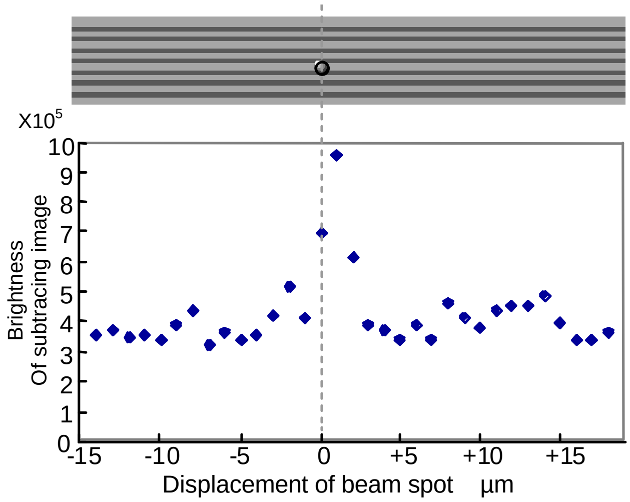

Figure 12. Relationship between brithness of subtracting image and displacement of beam spot

5 CONCLUSIONS

A new optical measurement system for detecting the semiconductor pattern defects based on the "laser scattering image" was developed. In order to verify the feasibility of application of our proposed method to patterned wafer inspection technique, several primary experiments were carried out. These results suggest that defects can be detected by comparing the laser scattering images between the patterned surfaces with and without defects. Since the laser scattering image is sensitive to the small features with size of 0.10 μm, our proposed has a feasibility of being applied on the pattern defects inspection for the next-generation linewidths.

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