Study on Particle Detection for Patterned Wafers by Evanescent Light Illumination

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Abstract
In modern semiconductor manufacturing processes, to realize high productivity and reliability of the semiconductor, patterned wafers inspection technology to maintain high yield become essential. However the conventional inspection technology can't apply to the inspection technique of patterned wafers for next generation semiconductors, because of the combination of smaller circuit features and vastly more complex processes. So, we attend to particles existing on the patterned wafer that particularly affects the yield. We propose the new evanescent light illumination method for evaluating the defects with the size of nanometer scale. In this paper, first, the evanescent light detection system was developed based on our proposed method. Next, evanescent light detection experiment was carried out for the tip of AFM probe with curvature radius of 5-10nm as a defect sample and this results suggested that the evanescent light illumination enables the nano-particles detection for the patterned wafer.

Introduction
Recently, to meet the demand for more powerful, high performance and multifunctional, integrated circuits (ICs), the semiconductor manufacturing processes focus attention on shrinking circuit features and higher circuit density. The semiconductor manufacturing introduces new materials such as copper and low-k dielectrics, new processing method and the transition to 300mm. As a result, yield management is more difficult because of more complex processes. Also, as circuit feature continue to decrease at an accelerated rate, the conventional defects inspection technology based on the imaging optics ultimately reaches diffraction limits imposed by the wavelength of incident laser beam. The conventional technology based on the light scattering systems using the propagating light illumination cannot distinguish the particle signal from the background noise caused by the patterned wafer of next generation.
So, we propose a new optical measurement method based on near field optics in order to detect small particle on patterned wafers, which is applicable to the inspection technique of patterned wafers for the next generation semiconductors. Instead of the propagating laser beam like conventional method, our proposed method uses the evanescent light that doesn't propagate but is localized, so that the background noise caused by patterned wafers is negligible. Therefore by using the proposed method based on evanescent light illumination, it is expected to sensitively detect the defects with the size of nanometer scale.

Particle detection method by evanescent light illumination
Fig.1 presents the concept of our proposed detection method. In this method, a converging annular light used as light source is incident on the hemispherical lens. When the incident angle (converging angle) is larger than critical angle, the total-internal-reflection condition is met at the bottom of hemispherical lens. So, evanescent light is generated at the bottom. The evanescent light illuminates the patterned wafer surface with a gap of several hundred nanometers. When the defects such as particles exist within the evanescent light, they scatter the evanescent light, and the scattered light passes through the hemispherical lens. Evanescent light decays exponentially away from the bottom of the hemispherical lens. If air gap is appropriately adjusted, the evanescent light effectively illuminates the particles on the patterned wafer, because it dose not reach the wafer surface. The hemispherical lens gathers the scattered light from the defects again, and it is detected as the Fourier transform image through the objective lens. The whole of wafer surface is inspected by scanning the hemispherical lens relative to the wafer surface. As mentioned above, the proposed method sensitively detects the nano-particles on the patterned wafer by the scattered evanescent light distribution using the dark-field of the annular beam.

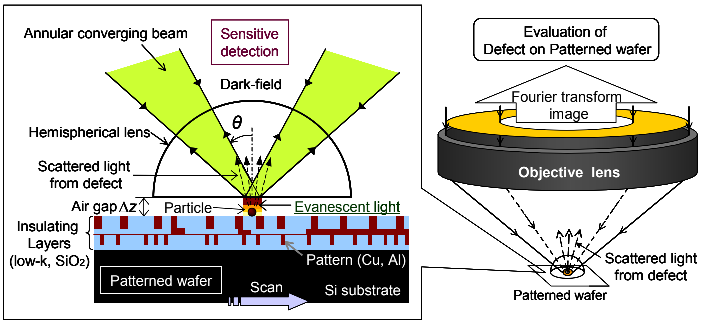

Fig.1 Concept of detection method by evanescent light illumination

Experimental optical system
Fig.2 presents the experimental schematic diagram. As light source, Ar^+ laser (wavelength=488nm; 30mW) is used. The annular beam transparency filter with light blocking film in the central part, whose diameter is 800 micrometers, transforms the incident beam into the annular beam. Through the objective lens (numerical aperture=0.73; working distance=4.7mm; focal length=2mm), the annular beam converges at the bottom of the hemispherical les (1.2mm in diameter; material: S-ALH79 (refractive index=2.003); with antireflective coat). The piezo electric translator1 precisely positions the objective lens for the hemispherical lens in the vertical direction. The piezo electric translator2 also precisely positions the hemispherical lens for the sample surface in the vertical direction. The hemispherical lens is moved in the horizontal direction by the micrometer caliper, and the optical axis of the hemispherical lens is adjusted to the optical axis of the objective lens. The scattered evanescent light from the sample is gathered by the hemispherical lens and the objective lens, and detected with the sensitive CCD area sensor (the size of pixel=6.7 micrometers square; the number of pixels=1300 (H), 1020(V); dynamic range: 12 bit).

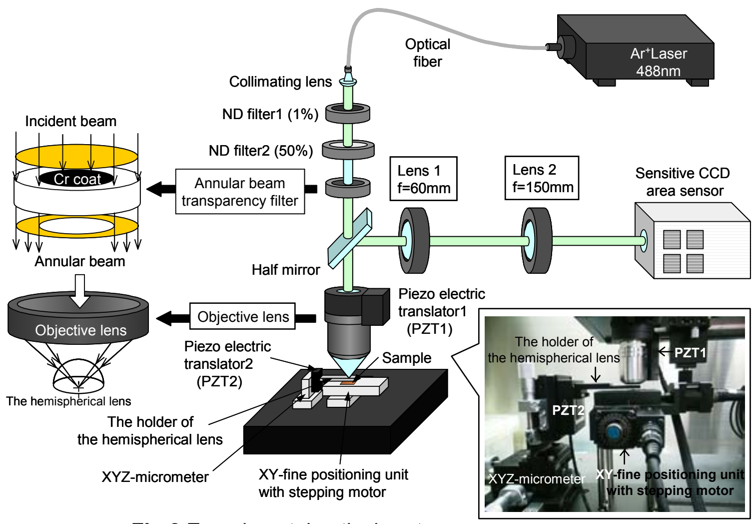

Fig.2 Experimental optical system

The sample is set at the XY-fine positioning unit with stepping motor (1step=0.5 micrometers). We verify the illumination characteristics of the experimental optical system. Fig.3 shows the intensity distribution without the annular beam transparency filter when the focal point of the objective lens is adjusted to the bottom of the hemispherical lens. In Fig.3, the darker area in the center of the intensity distribution and the brighter area on the outside are seen. The darker area is the area of transmitted light, because the light incident to the bottom of the hemispherical lens is transmitted at smaller angle than the critical angle of 29.95 degree. The brighter area on the outside is the total internal reflection area, because the light is reflected at the bottom of the hemispherical lens when the incident angle is larger than the critical angle. The boundary between the darker area and the brighter area corresponds to the critical angle. The diameter of the darker area is about 4.91mm (=733pixel multiplied by 6.7 micrometers). As calculated under the optical condition, it is about 4.99mm. So, the actual dimension is nearly equal to the calculated one.

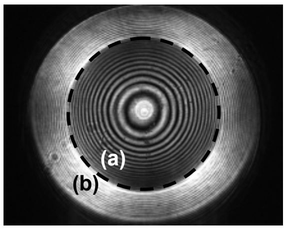

Fig.3 Intensity distribution without a sample
(a) Area of transmitted light
(b) Total internal reflection area

Scattered evanescent light detection experiments

Scattered evanescent light detection experiments are performed with the tip of the silicon single-crystal AFM probe as a defect sample. Fig.4 shows the SIM image of the AFM probe (curvature radius of the tip: 5-10nm; height of the probe: 10-15 micrometers). This probe is set at the XY-fine positioning unit with stepping motor.

Fig.5 presents the arrangement before the bottom of the hemispherical lens separates from the tip of the AFM probe. As shown in Fig.5, the tip of the AFM probe almost contacts the bottom of the hemispherical lens. The focal point of the objective lens is set at 4 micrometers above the bottom. In the Fourier transform image, the probe is placed on the lower side of the total internal reflection area. From this arrangement, the hemispherical lens is being moved 350nm upward. Fig.6 shows the changes of intensity distribution as the bottom separates from the tip. In the intensity distribution captured at the moment the bottom is 50nm above the tip (Fig.6 (a)), the scattered evanescent light caused by the tip is seen. As the bottom separates from the tip, the scattered evanescent light decreases. This is because the tip of the probe is being moved away from the evanescent light illumination area localized to the bottom. Computing amount of light intensity inside the area A that is shown in the distribution right above of Fig.7, the relation between the computed intensity and the displacement of the hemispherical lens is shown in Fig.7 ((a) without the tip, (b)with the tip). The evanescent light intensity scattered by the tip decrease rapidly as the moving distance of the hemispherical lens is long up to 200nm. This result reflects the characteristics of the evanescent light illumination that decays exponentially away from the bottom.

Under the condition that the tip of the probe almost contacts the bottom, the tip traverses the total internal reflection area. The result is shown in Fig.8. As the tip is moved, it is seen that the scattered light caused by the tip also moves.

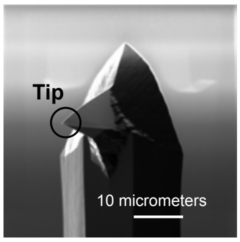

Fig.4 SIM image of AFM probe

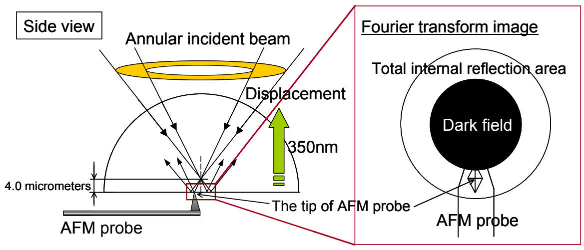

Fig.5 Arrangement for experiment

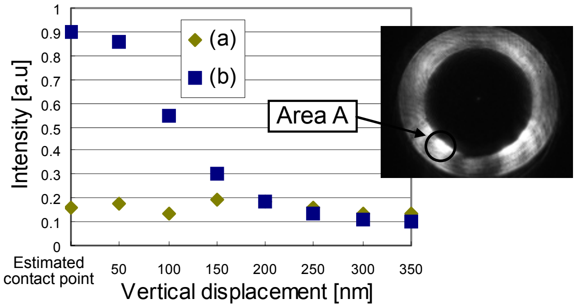

Fig.7 Relation between intensity and displacement of hemispherical lens
(a) without the tip (b) with the tip

Conclusion

We proposed a new optical detection method for evaluating the nano-defects existing on the patterned wafer by using evanescent light illumination and made the experimental optical system based on this proposed method. In this optical system, we verified the illumination characteristics of the proposed method. The results show that the area of transmitted light is in the center of the Fourier transform image and the total internal reflection area is on the outside, and that the boundary between these areas corresponds to the critical angle. Also we verified the capability of detection in the system using the tip of AFM probe as a defect sample. The system detects the scattered evanescent light caused by the tip, because the scattered light intensity characterizes the evanescent light.

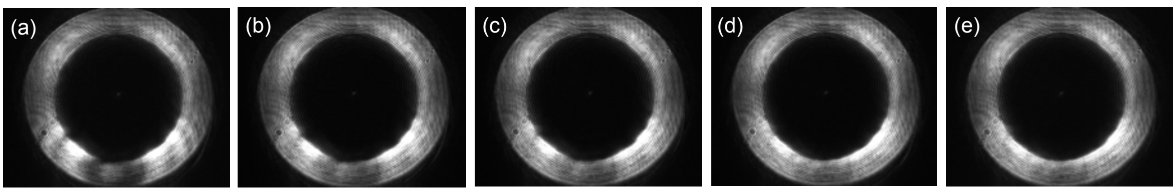

Fig.6 Changes of intensity distribution as the bottom of hemispherical lens separates from the tip of AFM probe
The bottom is (a) 50nm (b) 100nm (c) 150nm (d) 200nm (e) 250nm above the tip

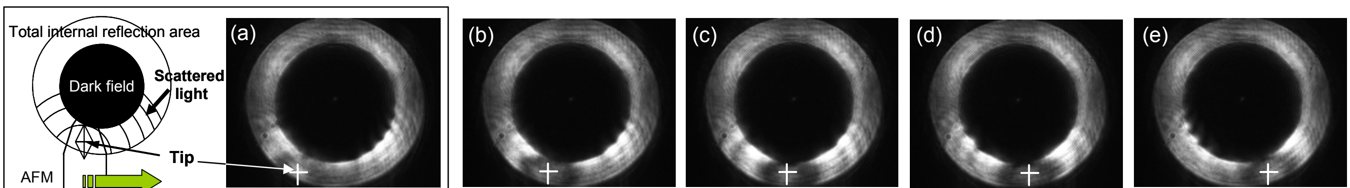

Fig.8 Changes of intensity distribution as AFM probe is moved
(a) initial position, moving distance of (b) 0.5 (c) 1.0 (c) 1.5 (d) 2.0 (e) 2.5 micrometers