125 Study on Particle Detection for Patterned Wafers by Evanescent Light Illumination -Evanescent Light Scattering Simulation by means of FDTD Method-

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Summary

The conventional defects inspection technology can't apply to an inspection technique of patterned wafers for the next generation semiconductors, because of physical limits imposed by the wavelength of incident beam. So, we attend to particles existing on the patterned wafer that particularly affects the yield and propose new optical detection for evaluating the nano-particles by using evanescent light based on near field optics. In this paper, to verify the feasibility of this proposed method, computer simulation was performed by means of FDTD method based on Maxwell's equations. The results show that the proposed method is effective for detecting particle (100nm in a diameter) on patterned wafer of 100nm lines and spaces.

Keywords: Evanescent light, Particle contamination, Patterned wafers

1. Introduction

In modern semiconductor manufacturing processes, to realize high productivity and reliability of the semiconductor, patterned wafers inspection technology to maintain high yield becomes essential. Especially particle detection is one of most important technology for next inspection technology. According to International Technology Roadmap for Semiconductors (ITRS) feature sizes of semiconductors circuits continue to decrease at an accelerated rate and along with it more layers, changing materials and larger wafer sizes have made a complex process. However the conventional defects inspection technology ultimately reaches physical limits imposed by the wavelength of incident laser beam. As shown in Fig.1, the problem of the conventional technology for next generation processes is that the propagating light illumination cannot distinguish the particle signal from background scattering noise induced by patterned wafer, because the propagating light illuminates the patterned wafer as well as the particles on it.

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 an 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 localizing energy, so that the background scattering noise induced 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.

2. Particle detection method by evanescent light illumination

Figure 2 presents the concept of our proposed detects inspection method. In this method, a converging annular light used as light source is incident on the hemispherical lens. When the angle of incident (converging angle) θ is larger than critical angle, it achieves the total-internal-reflection condition within hemispherical lens. So, evanescent light is generated at the bottom of hemispherical lens, which doesn’t transmit from the bottom of hemispherical lens to air, thus is known to be localizing energy near by the generated surface. If the scatterer such as particles exists within the evanescent light, they scatter the evanescent light, and the scattered light travel upward. The hemispherical lens with evanescent light is moved closer to the patterned wafer surface with a gap of several hundred nanometers. Because evanescent light decays exponentially away from the bottom of the hemispherical lens, if air gap is appropriately controlled, it will be possible that the particles on patterned wafers are illuminated effectively without illuminating on the patterned wafers. The scattered light from the particles is gathered again by the hemispherical lens, and it is detected as scattered light distribution from the particles through the objective
lens. The hemispherical lens scans fast the patterned wafers and inspects whole wafer surface. As mentioned above, the proposed method detects sensitively the nano-particles on the patterned wafer by scattered evanescent light distribution using dark-field of annular beam.

![Diagram of particle detection method by evanescent light illumination](image)

**Fig.2 Concept of particle detection method by evanescent light illumination**

### 3. Computer model for simulation

![Simulation model (base model)](image)

**Fig.3 Simulation model (base model)**

![Simulation result of base model](image)

**Fig.4 Simulation result of base model**

In order to verify the feasibility of this proposed method, we have developed a computer simulation to solve Maxwell’s equations based on the 2-dimensional finite-difference-time-domain (FDTD) method. The FDTD method is formulated by derivatives Maxwell’s curl equations over a finite volume and approximating the derivatives with centered difference approximations \((2)\) \((4)\). By using computer simulation, we analyzed electromagnetic field of our proposed optical system.

The diagram of simulation model that don’t set scatterers, which is called base model, is depicted in figure 3. As shown in this figure, by way of example, the hemispherical lens \((n=2.003, n; \text{refractive index})\) and the SiO\(_2\) \((n=1.46)\) filmed wafer (film thickness\(=150\)nm) are set. The hemispherical lens is approached toward the surface with the air gap of \(150\)nm. The incident light is set as p-polarized plane wave at \(488\)nm wavelength (Ar\(^+\) laser) and the incident angle is taken at \(35^\circ\). The unit grid length is \(5\)nm in the \(940\times 1000\) unit space.

Figure 4 shows the result. It is gray-scale representation of time-average field intensity distribution. In the intensity level, white color presents high level and black is low. Here, the field intensity means squared electric field \(|\mathbf{E}|^2\). In the hemispherical lens, the interference pattern results from the interference by incident and reflected light. This result shows the evanescent light is generated at the bottom of the hemispherical lens and illuminates the surface of the SiO\(_2\) filmed wafer.

### 4. Basic validation of the proposed concept

Using the computer simulation mentioned before, we analyze electromagnetic field placed the scatterer (Fig.5). A Cu single pattern (the size has \(100\times 100\)nm) with a Cu-line in the SiO\(_2\) film shown in Fig.5 (A) is modeled (called a pattern model). A particle (Cu; \(100\)nm in a diameter) on the SiO\(_2\) film shown in Fig.5 (B) is modeled (called a particle model). Fig.5 (a) shows that the intensity distribution is changed with a scatterer and that the scattered light transmits to hemispherical lens in both models. To evaluate the scattered light by a scatterer in more detail, the intensity distribution in a pattern model is subtracted from one in base model. Also the scattered light intensity distribution in a pattern model is subtracted from one in base model. Thus by deleting incident and reflected light within the hemispherical lens of each original image, the scattered...
light distribution is enhanced (Fig.5 (b) the subtractive image). By comparison between the subtractive images in a pattern and in a particle, the scattered light by a particle is seen to be brighter than by a pattern. Additionally to evaluate quantitatively, we compute amount of light intensity inside the dotted line in the each subtractive image. The scattered light intensity is 626 in a pattern model, and is 1959 in a particle model. As the surface of scatterer separates from the hemispherical lens, the scattered light intensity from the surface decreases. The particle scatter is located at nearer distance than the pattern scatter from hemispherical lens. Therefore the scattered light intensity from a particle on the SiO2 film has a high value to be about three times of one from a pattern in the SiO2 film.

![Fig.6 Simulation result of (A) a pattern model and (B) a particle model](image)

(A) a pattern model  
(B) a particle model

Fig.5 Simulation result of (A) a pattern model and (B) a particle model

(a) original image  (b) subtractive image

5. Computer simulation of patterned wafer

5.1 The evanescent light scattering from a particle on patterned wafer

In order to investigate the evanescent light scattering from a particle wafer, we carried out the computer simulation of patterned wafer model. In this simulation, we set patterned wafer model as multi-pattern with many Cu lines (the size has 100×100nm) in SiO2 film of base model as shown in fig.6. In this case, we also set single particle (Cu: 100nm in a diameter) on SiO2 film. Fig.7 show the simulation result meaning subtractive images (without particle (a), with particle (b)). These images show that the scattered light distribution from the patterned wafer transmits to the hemispherical lens, and the scattered light from the particle is brighter than from the patterned wafer without particles. Computing amount of light intensity inside the dotted line (shown in Fig.6) in the each subtractive image, it is 2494 without particle, and 7012 with particle. This result shows the proposed inspection method can detect the particle on the patterned wafer with S/N ratio of 2.81.

5.2 Relation between the scattered light intensity and S/N ratio, and air gap

Fig.8 presents the relation between the scattered light intensity and air gap. Signal and noise mean scattered light intensity from patterned wafer with and without particle, respectively. Fig.8 indicates the intensity of both
signal and noise shows a similar tendency to decrease exponentially as air gap become larger. Fig.9 shows the relation between S/N ratio and air gap. S/N ratio increases from 2.76 at 100nm to 3.78 at 250nm, thus has the highest point at 250nm. And it decreases rapidly. The scattered light intensity decreases as air gap become larger and it is near by zero at 400nm. However there exists appropriate air gap for sensitive detection, as an example, it is estimated to be 250nm for 100nm particle size. Thus, the result suggests that this method enables to detect particle defects with high sensitivity if air gap is appropriately adjusted.

![Simulation result of patterned wafer model (subtractive image)](image)

Fig.7 Simulation result of patterned wafer model (subtractive image) in the case of air gap = 150nm (a) without particle (b) with particle

![Relation between the scattered light intensity and air gap](image)

Fig.8 Relation between the scattered light intensity and air gap (a) Signal light from a particle on patterned wafer (b) Noise light from the patterned wafer without a particle

![Relation between S/N and air gap](image)

Fig.9 Relation between S/N and air gap

6. Conclusions

We proposed a new optical detection method for evaluating the nano-particles existing on the patterned wafer by using evanescent light illumination and verified the feasibility of this proposed method by the developed FDTD simulation. The results obtained in this paper are as follows;

1. As the surface to be measured separates from the hemispherical lens, the scattered light intensity from the surface decreases exponentially. Therefore the scattered light intensity from a particle on the pattern surface has a high value to be about three times of one from the pattern surface without a particle.

2. When air gap between the hemispherical lens and patterned wafer (Cu; the size has 100×100nm) is set at 150nm, this method detects the particle (Cu; 100nm in a diameter) on patterned wafer of 100 nm line and space with S/N ratio of 2.81.

References