Experimental Verification for Super-resolution Optical Inspection for Semiconductor Defect by using Standing Wave Illumination Shift

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Abstract. Semiconductor design rules and process windows continue to shrink, so we face many challenges in developing new processes such as less 100nm design rule and 300mm wafer [1]. The challenges have become more difficult and the next generation defect inspection is urgently demanded. The optics and electron beam have been mainly used for detect of the critical defects, but both technologies have disadvantages. The optical inspection is generally not enough sensitive for defects at 100nm geometries and below, while the SEM inspection has low throughput because it takes long time in scanning 300mm. In order to find a solution to these problems, we proposed the novel optical inspection method for the critical defects on the semiconductor wafer. For fundamental verification of the resolution property of the proposed method, we carried out the experiments to resolve nano-structures with super-resolution. In the experiments, to suggest the possibility of higher resolution than the Rayleigh limit depended on NA of an objective lens, we used the objective lens with relatively low NA (0.46) in the imaging optics, and we used the wafer with 500nm-sized line and space patterns as sample. As a result, the 500nm-spaced line edge pattern were resolved clearly by using the super-resolution method, although the Rayleigh limit of the imaging optics is 647nm.

Introduction

According to the ITRS roadmap [1], the semiconductor defects inspection system for next-generation is urgently demanded, and requirement for sub-100-nm nodes and difficulty of defect detection challenge increase exponentially with shrinking design rules. One of the most important key-requirements is the defect detection of semiconductor wafer [2]. Defects in the wafer inspection field include random defect like killer particles, clustered defect, scratch defect and so on. These defects deteriorate electrical chip performance and process yield in factory line. Especially, the inspection of the patterned wafer is one of the key-requirements for the next generation.

Optical method and electron beam are conventionally used for the semiconductor wafer inspection [3]. However inability of the optical inspection with the continuous miniaturization of interconnects has become the big issue. Electron beam is not useful for wider wafer inspection because it has low throughput property. We focused attention on the optical inspection because it has non-destructiveness, high throughput and potential for high resolution for sub-100nm inspection. In optical wafer inspection, resolution and defect detection beyond the Rayleigh limit are now required due to accelerating pattern miniaturization and development of advanced semiconductor devices [4].

One of the Solutions to challenges in semiconductor optical inspection is the use of a shorter wavelength, which has been studied as countermeasures against device miniaturization. However, the shortening of wavelength cannot keep up with the challenges and has a limit, so we propose the novel super-resolution inspection technique. When a pattern is miniaturized and made dense, light reflected from the wafer becomes weak, and the captured image becomes dark with low contrast, so we must develop high sensitive method and it must be able to obtain a lot of optical information [5]. Our super-resolution inspection technique combines standing wave illumination shift method with dark-field imaging technology to deliver optimal sensitivity for critical defect detection at sub-100-nm nodes and beyond without compromising on throughput. Standing wave illumination shift method enables the inspection optics to resolve patterns that the conventional method cannot. Nano-scale shift of illumination and the super-resolution post-processing are keys to achieving the resolution enhancement and higher sensitivity for the defect detection.

Methodology

Standing Wave Illumination Shift and Scattered Light Modulation. We show the schematic explanation of the standing wave illumination shift and the scattered light modulation in figure 1. The standing wave illumination is generated by 2-beam interference with an objective lens. The standing wave illumination is scattered by the sample surface, and the scattered light is focused on the CCD imaging surface through the imaging lens. The standing wave is shifted at nano-scale by phase difference between 2-beam in the illumination (figure 1(a)). And then, the scattered light is modulated by the shift of the standing wave illumination (figure 1(b)). The super-resolution image can be calculated from multiple images by the super-resolution image reconstruction algorithm.

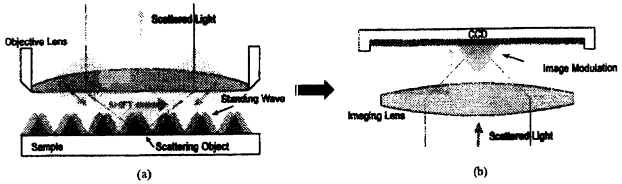


Figure 1. The schematics of the standing wave illumination shift and the scattered light modulation

Super-resolution Image Reconstruction Algorithm for Post-processing. We show the schematic block diagram of the super-resolution post-processing in the figure 2. Firstly, the sample is illuminated with standing wave illumination, and the multiple images are experimentally observed by the standing wave shift. And then, the simulated multiple images are computationally calculated. The error between the observed images and the simulated images is approximately fed back to assumed sample, so we obtain the reconstructed sample. The image reconstruction is iteratively calculated with successive approximation until the error is converged. The nano-shifts of standing wave illumination that is modulated in about half-wavelength scale include high-frequency spatial information and this causes change to scattered light images. We expect to achieve super resolution by feeding back the errors in scattered light images into sample distribution and reconstructing the sample distribution with successive approximation.

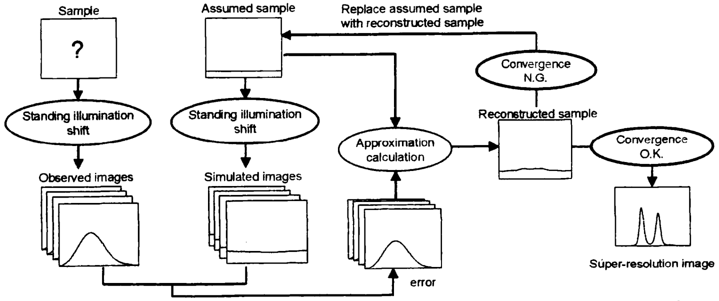


Figure 2. The schematic block diagram of the super-resolution post-processing

Experiment

1D Super-resolution Experiment for the Line and Space Pattern. For experimental verification of resolution enhancement by using the super-resolution method, we performed the 1D super-resolution experiment for the line and space pattern shown in figure.3 observed with optical microscope (NA = 0.95, Rayleigh limit = 300nm). The experimental setup is shown in table 1. It is expected that the super-resolution method make it possible to observe a structure with higher resolution beyond the Rayleigh limit depended on NA of an objective lens. And as the verification of the essence of the method, we used the objective lens with relatively low NA (0.46, Rayleigh limit = 647nm). In scattered light imaging, the scattered light from line edges is mainly detected with the photo-detector, so the line edges are resolved with the super-resolution method. In this experiment, the sample was tilted to find out whether the line and space were appropriately resolved. The results and the tilt of the sample are shown in figure.4, in which (a) shows 500nm line and space (tilt = 0 deg) result, (b) shows 522nm line and space (tilt = 17 deg) result, (c) shows 777nm line and space (tilt = 50 deg) result respectively. The figure.4 shows, periodic distributions of the super-resolution results were corresponding to edges of the line and space sample, and the 500nm-spaced line edges were clearly resolved beyond the Rayleigh limit (647nm) by using the super-resolution method.

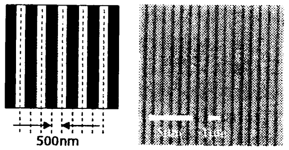
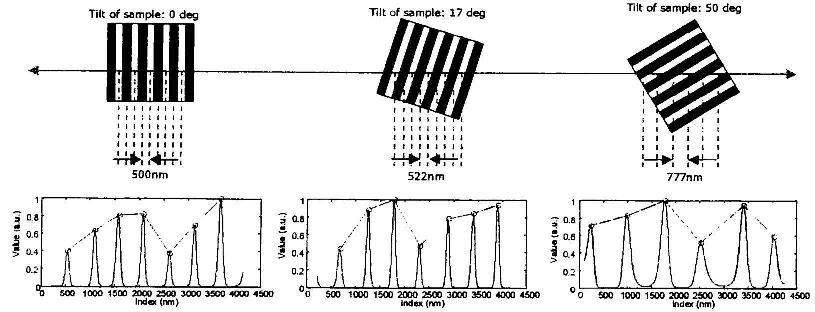


Figure 3. Line and space sample

Table.1 Experimental setup for super-resolution

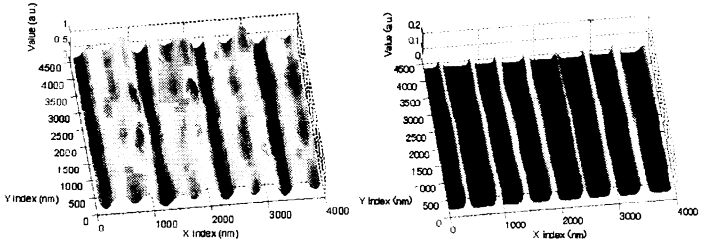
Illumination light	Wave length: 488nm
Pitch of standing wave	1200nm
Numerical aperture of objective lens	0.46
Magnification of imaging optics	38
Standing wave shift step size	80nm
Iteration times	10



(a) 500nm-spaced line edges (b) 522nm-spaced line edges (c) 777nm-spaced line edges

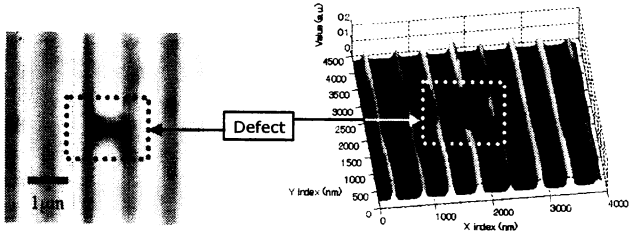
Figure 4. 1D super-resolution distribution of periodic line edges

2D Super-resolution Experiment for Defect Inspection in the Line and Space Pattern. The line and space pattern have nano-structure only in lateral direction, so we can obtain 2D super-resolution image by setting 1D super-resolution distributions in longitudinal direction. And the experimental setup was same as 1D experiment mentioned above. The figure.5 shows the 2D super-resolution image of 500nm-spaced line edges (b), and coherent scattered light image with high NA (0.95, Rayleigh limit = 313nm) optics (a). It was found out in this figure, by using relatively low NA (0.46) optics and the super-resolution method, the 500nm-spaced line edges are clearly resolved beyond the Rayleigh limit compared with the scattered light image. The figure.6 shows 2D Super-resolution image of the sample including defect (b) and the sample image observed with high-resolution (Rayleigh limit = 300nm) optical microscope (a). It was confirmed; the 500nm-sized defect on the line and space was detected with relatively low-resolution (Rayleigh limit = 647nm) optics and the super-resolution method.



(a) Scattered light image with NA(0.95) (b) 2D super-resolution image with NA(0.46)

Figure 5. 2D Super-resolution image of 500nm-spaced line edges



(a) Line and space sample including defect (b) 2D super-resolution image with NA (0.46)

Figure 6. 2D Super-resolution image of the sample including defect

Conclusions

In order to verify the super-resolution method experimentally, we performed the super-resolution experiment to resolve the 500nm line and space sample including defect. As a result, the 500nm-spaced periodic edge patterns were clearly resolved beyond the Rayleigh limit (647nm), and the 500nm-sized defect on the line and space was detected. So it is suggested that our super-resolution method can be used for the optical defect inspection of the next generation semiconductor wafer.

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