Design Value Use Type Super-Resolution Optical Inspection for Microfabricated Structure Defects by using Standing Wave Illumination Shift

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Abstract: The demand which detects the defect of a detailed structure is increasing. However the resolution of the general optical inspection method is not enough. In order to raise resolution, utilizing the advantage of optical detection, we proposed the novel optical inspection method. Although the steady value was conventionally set up as an initial value of processing, a design value is set as an initial value in this research. As a result, highly precise defective detection is attained rather than the conventional technique. Moreover, the possibility of the detection using low magnifying power is confirmed.

Keywords: **standing wave illumination, image reconstruction, super-resolution, designed value**

1. INTRODUCTION

With development of nanotechnology, miniaturization of microfabricated structure with an engineering function including semiconductor devices [1] and optical function devices such as photonic crystals [2] and polarization controls [3] is progressing. Although the demand which detects the defect of a detailed structure at 100nm geometries and below is increasing, the resolution of the general optical inspection method is not enough for this purpose because of Rayleigh limit. However, there is a merit of a high speed and not destroying in optical inspection. In order to raise resolution of optical inspection, utilizing the advantage of optical method, we proposed the novel optical inspection method for the critical defects on the microfabricated structure. Until now, resolution which is beyond Rayleigh limit is theoretically studied and experimentally bought to realization by proposed method [4] [5]. Although the steady value was conventionally set up as an initial value of processing, a design value is set as an initial value in this study. It aimed at enabling highly precise detection by using design value. The resolution characteristics of the former type super-resolution technique and design value use type method are examined. In the super-resolution using a design value, it is examined whether the defect which is not included in the design value is detectable. It is examined that more highly precise defective detection can be performed by new method. It is examined whether defective detection is possible from the large discretization data obtained from the optical system of low magnifying power. If defective detection is possible using the optical system of low magnifying power, it will become possible to observe a larger domain collectively, and improvement in the speed of this technique will be attained.

2. METHODOLOGY

2.1. Standing wave illumination shift and scattered light modulation

The outline of the resolution improving method by standing wave shift is described below. The standing wave illumination is generated by 2-beam interference. 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. And then, the scattered light is modulated by the shift of the standing wave illumination. The super-resolution image of scattering efficiency can be calculated from multiple images by the super-resolution image reconstruction algorithm.

2.2. Super-resolution image reconstruction algorithm for post processing

The schematic block diagram of the super-resolution post-processing is shown in the Fig. 1. 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, based on Fourier optics. The error between the observed images and the simulated images is approximately fed back to assumed sample, so we obtain the reconstructed sample. The initial value of this assumed sample was formerly a steady value. In this research, the resolving characteristic at the time of inputting a design value as

an initial value is verified. 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.

Fig. 2 (a) is distribution of assumed sample. Fig. 2 (b) is normal microscopic image of uniform illumination: bandwidth-limited image by NA. It is confirmed that structure of sample is not resolved in Fig. 2 (b).
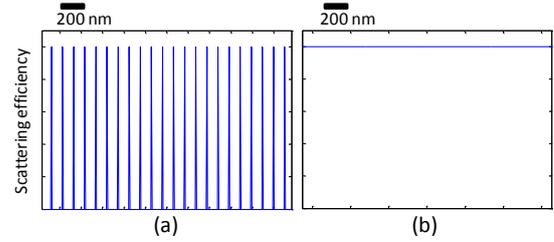
3. COMPARISON OF THE CONVENTIONAL SUPER-RESOLUTION AND THE DESIGN VALUE USE TYPE SUPER-RESOLUTION

3.1. Super-resolution of periodic structure without a defect

For verifying the feasibility of the design value use type super-resolution method, we carried out computer simulation based on Fourier optics. First, the periodic structure of 104 nm pitch is employed supposing the semiconductor pattern to investigate fundamental characteristic of the design value use type super-resolution. Super-resolution simulation setup is shown in Table1.

Fig. 2. (a) 104 nm pitch sample,
(b) Normal imaging of *NA*0.95

The examples of resolving of the sample by conventional super-resolution which made the initial value the steady value are shown in Fig. 3. Iteration time is Fig. 3 (a) 2 time, (b) 100 time, (c) 10000 time. Although sample structure cannot be reconstructed in Fig. 3 (a) and (b), periodic structure is reconstructed in Fig. 3 (c).

Table1. Simulation setup

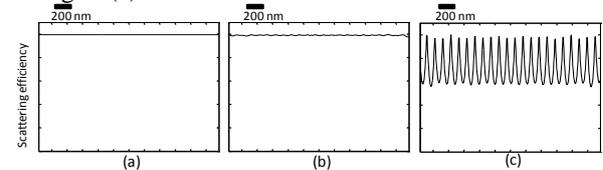|	
Wavelength of source	488 nm
Pitch of structured light illumination	247 nm
NA of objective	0.55
Rayleigh limit	541 nm
Shift times	10
Shift step size	22.5 nm
Iteration Time	2, 100, 10000
1-pixel cover domain	6.5 nm

Fig. 3. Examples of conventional super-resolution. Iteration time is (a) 2 time, (b) 100 time, (c) 10000 time.
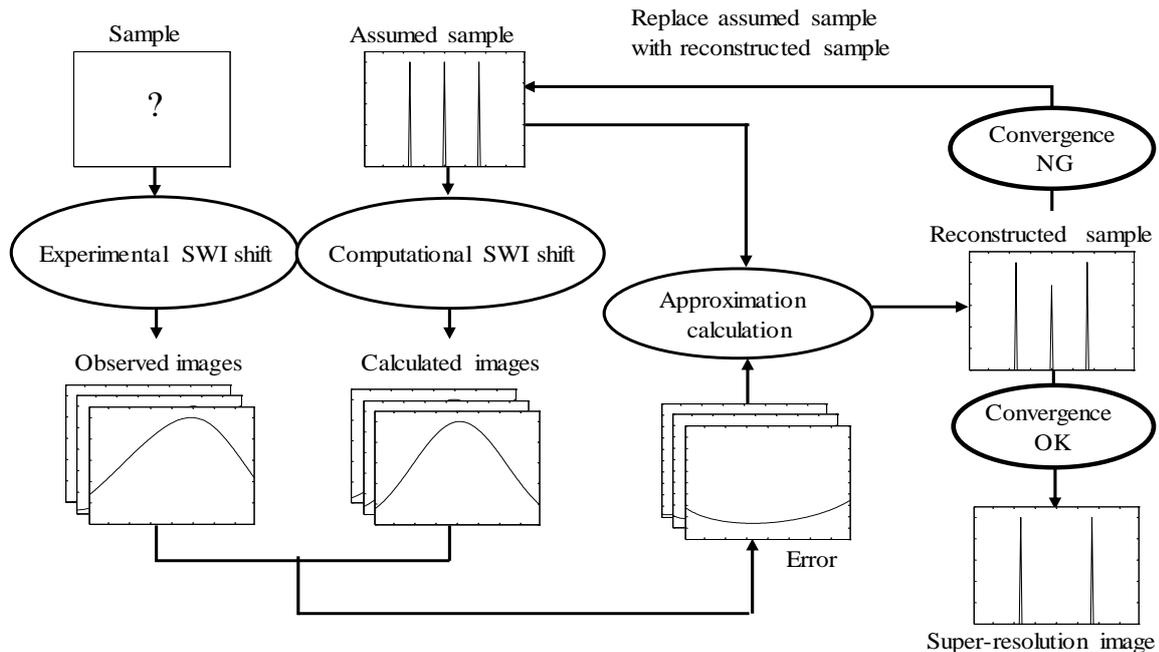
Fig. 1. The schematic block diagram of the super-resolution post-processing

On the other hand, the super-resolution results at the time of giving the design value shown in Fig. 2 (a) as an initial value are shown in Fig. 4. The structure of a perfect sample can be acquired also in a case with little number of iteration time.
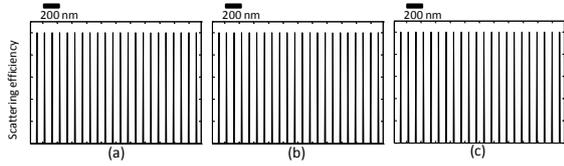

Fig. 4. Examples of design value use type super-resolution. Iteration time is (a) 2 time, (b) 100 time, (c) 10000 time.

3.2. Super-resolution of periodic structure with a defect

It is verified by super-resolution whether defective detection is possible in the case where a defect exists in periodic structure. The sample which set the defect to the periodic structure of 104 nm pitch is Fig. 5 (a). Periodic structure without a defect as a design value as shown in Fig. 5 (b) is set up. The result of having performed super-resolution processing to this sample is shown in Fig. 6. Iteration time is set as 10000 time. Fig. 6 (a) is the result of being based on the conventional super-resolution. Although it succeeds in defective detection and periodic structure is also reconstructed, the reproducibility of the intensity direction is not good. On the other hand, by the result of design value use type super-resolution, it is reconstructing nearly completely, including the structure of a sample to the intensity direction. Even if the information which does not have a defect as a design value was inputted, it confirmed that a defect was detectable.
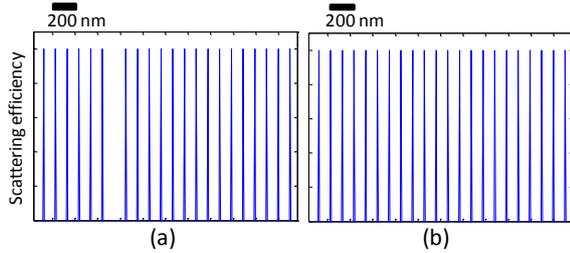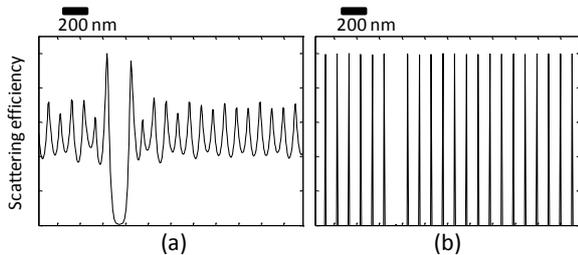

Fig. 5. (a) Sample, (b) Designed value.

Fig. 6. The result of (a) conventional super-resolution, (b) design value use type super-resolution.

3.3. Influence investigation of discretization

Super-resolution is performed using data with larger discretization than a design value, and the influence of discretization is considered. Modulated scattering light images when a standing wave illumination shift is performed to the sample of Fig. 5 (a) are shown in Fig. 7. The 1-pixel cover domain of Fig. 7 (a) is 6.5 nm like Table1. Each line shows scattering light image of 11 obtained when standing wave is shifted 10 times. Each line is the picture which was obtained in standing wave illumination - position n (SWI-Pn). n is the integers from 1 to 11. Fig. 7 (b) shows the data dicretization is large, and a 1-pixel cover domain is 52 nm. When super-resolution is performed using the large discretization data as shown in Fig. 7 (b), the influence which it has on a result was investigated. Since 1-pixel 6.5-nm structure is resolved using the large discretization data (1-pixel cover domain is 52 nm), this processing is equivalent to reconstructing the structure of a subpixel. Fig. 8 shows the result of carrying out super-resolution using the information on Fig. 7 (b). Iteration time is set as 10000 time. By the conventional super-resolution, as shown in Fig. 8 (a), structure of a sample cannot be reconstructed. In the result of design value use type super-resolution of Fig. 8 (b), although it is uneven in the intensity direction compared with the result of Fig. 6 (b), the structure of the sample of Fig. 5 (a) can be reconstructed. Even when the large discretization data was processed, the superiority of the design value use type super-resolution is confirmed. Moreover, defective detection is possible by new method.
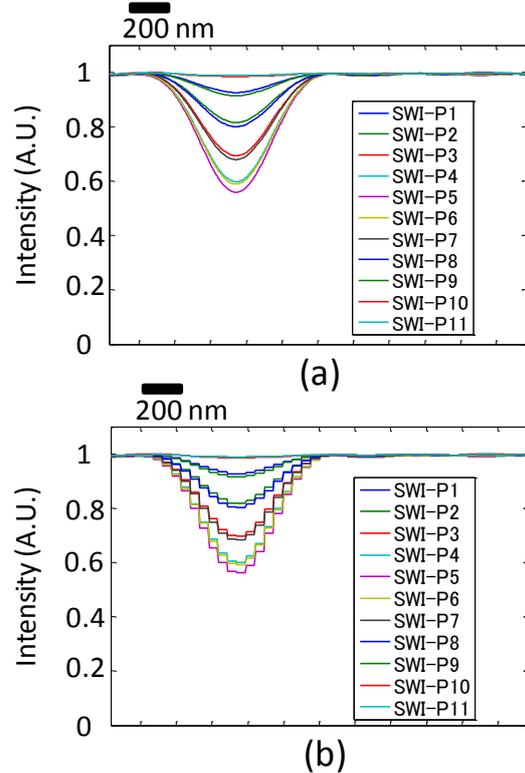

Fig. 7. Modulated scattering light images which (a) discretization is small, (b) discretization is large
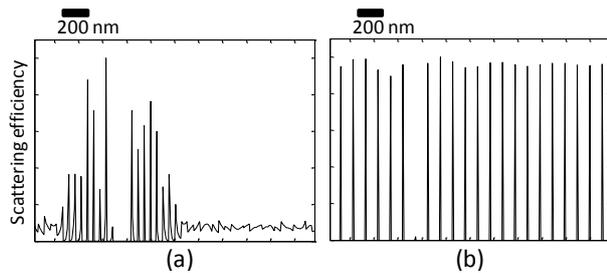
Fig. 8. The result of (a) conventional super-resolution, (b) design value use type super-resolution.

4. CONCLUSIONS

Aiming at making super-resolution technique using standing wave illumination shift more highly precise, the design value use type super-resolution was proposed. It was confirmed in comparison of the conventional method and the new method that the new method is more highly precise. The superiority of the new method was shown in defective detection. In super-resolution processing in which the large discretization data was used, although reconstruction of the structure and the defect of a 104-nm pitch were not reconstructed in the conventional technique, it succeeded in reconstruction of the structure which includes a defect in a new method. There is possibility of the high precision defective detection using the optical system of low magnifying power. The improvement in the speed of super-resolution by carrying out processing of the large domain is expected. Defective detection of 100-nm pitch structure is possible even using the optical system of low magnification of 40 times. This means that our proposed method allows 100 nm-resolution defects inspection for a wide area of 375 μm * 375 μm in the case of a CCD camera with 1-pixel 5μm and 3000*3000 pixels.

In future work, the influence of complex form objects including various kinds of defects will be investigated and experimental examination will be performed.

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