Sub-nanometer Uncertainty Evaluation of Line Width Measurement by Si Lattice Structures of STEM Image

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Abstract

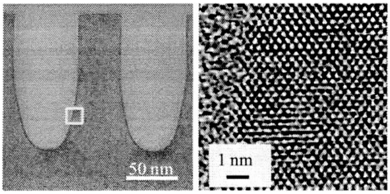
The novel calibration method of sub-nanometer accuracy for line width measurement using STEM images is proposed. In accordance with the proposed method, the traceability of line width standards is established using Si lattice structures and uncertainty evaluations. First, we define the edge of a line at the end of Si lattice structure as the interface between Si lattice and oxide film. Second, an image magnification is calculated using 2D Fourier analysis of the STEM image. Third, the edge positions of the line are detected using local standard deviations after noise reduction method. Then, the uncertainty is evaluated with the uncertainty contributors of pixel size and edge detection. Using the proposed method, the expanded uncertainty less than 0.5 nm for the line width of 45 nm is established.

1 Edge detection from STEM image

We use STEM (Scanning Transmission Electron Microscope) images of Si line pattern to establish the novel method of sub-nanometer accuracy for the line width measurement [1][2]. First, the edge position is defined at the interface between Si lattice structure and oxide film. Then, we proposed the novel method for averaging the images and detecting the edge of the line width.

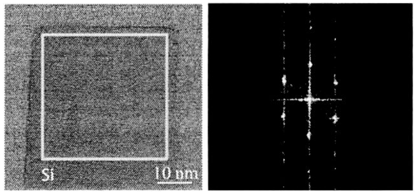
1.1 Image parameters of STEM image by 2D Fourier analysis

A thin specimen of Si line pattern of 100 nm is sliced by FIB (Focused Ion Beam) micro sampling system. Figure 1 shows an example of STEM image of the specimen by magnification of 3,000,000. Si lattice structures are clearly investigated on Figure 1 (b). Figure 2 illustrates peaks on a frequency domain image of Si lattice structure by 2D Fourier analysis. From positions of these peaks, the pixel size of the image is calculated.



(a) (b)

Figure 1: STEM image; (a) image, and (b) Si lattice structure

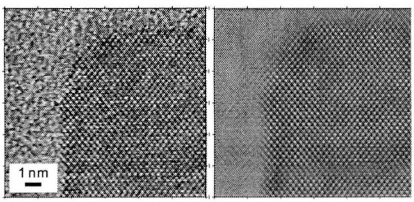


(a) (b)

Figure 2: 2D Fourier analysis; (a) image, and (b) peaks in frequency domain image

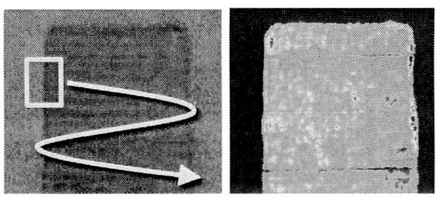
1.2 Averaging method and edge detection

Before the edge detection, we applied the novel averaging method for reduction of random noises of the image. The size of a stencil pattern for averaging is decided by Si lattice size. Figure 3 shows the image before and after the averaging. Then, the local standard deviation is calculated on the STEM image for detecting inside or outside of Si lattice structure. Figure 4 shows the local standard deviation map using the specified frame. The edge of Si lattice structure is clearly detected using the map.



(a) (b)

Figure 3: Averaging of STEM image; (a) before, and (b) after averaging



(a) (b)

Figure 4: Local standard deviation map (a) frame for std., and (b) local std. map

1.3 Example of edge detection

Figure 5 illustrates an example of edge detection under the conditions in Table 1. The proposed method as follows:

(a) STEM image by magnification of 2,800,000 and accelerating voltage of 200 kV. The pixel size is 0.04428 nm by 2D Fourier analysis.

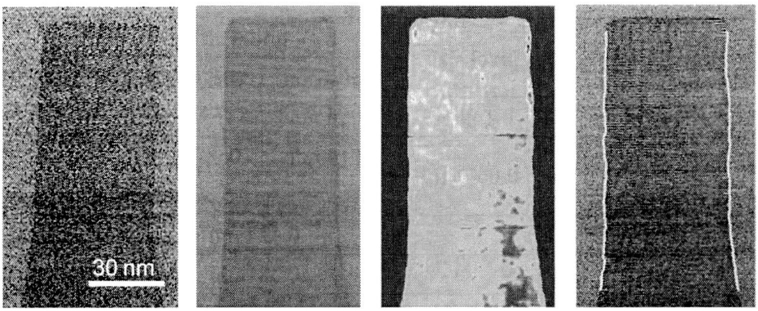
(b) Averaging image by stencil of 18 × 26 pixels size.

(c) Local standard deviation map by frame of 16 × 24 pixels size.

(d) Edge detection by 50 % threshold level on the local standard deviation map.

Table 1: Experimental conditions for the edge detection in Figure 5

items	descriptions
STEM image	magnification of 2,800,000, accelerating voltage of 200 kV
image size	1600 × 3500 pixels from 4096 × 4096 pixels
pixel size	0.04428 nm/pixel
averaging stencil size	18 × 26 pixels
standard deviation frame size	16 × 24 pixels



(a) (b) (c) (d)

Figure 5: Example of edge detection; (a) STEM image, (b) averaging, (c) local standard deviation map, and (c) left and right edges

2 Uncertainty evaluation for the line width calculation

The uncertainty of line width measurement is evaluated by four contributors shown in Table 2. The uncertainty from pixel size is estimated by variation of the pixel sizes at four positions in Figure 6 (a) as 0.149 %.

The uncertainty by line width detection is estimated from three contributors as effect of the detected position on Y axis, variation of threshold level and repeatability of the deferent images. The uncertainty by Y axis position is evaluate in 0.9 nm range on four positions in Figure 6 (b) as 0.014 nm, that by threshold level is evaluated from the variation of threshold level in Figure 6 (c) as 0.007 nm, and that by repeatability is evaluated from three iterations at 0.107 nm.

As the result of these evaluations, the total uncertainty from line width detection is 0.108 nm. Then, the combined standard uncertainty is evaluated at 0.127 nm and the expand uncertainty (3σ) is 0.381 nm for line width of 45 nm.

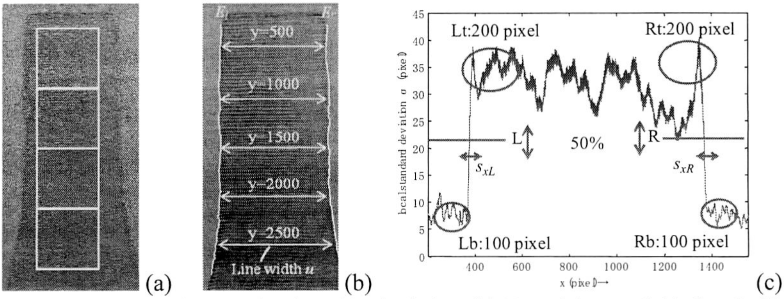


Figure 6: Uncertainty evaluation; (a) pixel size, (b) Y position, and (c) threshold

Table 2: Uncertainty evaluation for the line width calculation (line width is 45 nm)

contributors	pixel size	line width detection		
		Y position	**threshold**	**repeatability**
evaluation	0.149 %	0.014 nm	0.15 pixel	0.239 %
standard uncertainty (measured)	0.067 nm	0.014 nm	0.007 nm	0.107 nm
		0.108 nm		
combined standard u.	0.127 nm			
expand uncertainty 3σ	0.381 nm			

3 Conclusions

The novel method of sub-nanometer accuracy for the line width measurement using STEM images is proposed. In the proposed method, the traceability of line width standards is established using Si lattice structures. The proposed method was applied to an example of Si line specimen, and the line width is calculated with the expand uncertainty (3σ) of 0.381 nm. In future works, we will compare the line width by STEM images using the proposed method and the results by CD-SEM images and CD-AFM images on the same line position. Then the detailed estimation of the uncertainty of the proposed method is calculated.

References:

[1] Takamasu, K., et al., "Sub-nanometer calibration of CD-SEM line width by using STEM," SPIE advanced lithography 2010 (2010).

[2] Hasler-Grohne, W., et al., "Calibration procedures and application of the PTB photomask CD standard," Proc. SPIE 5992, 59924O (2005)