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Sub-Nanometer Line Width and Line Profile Measurement Using STEM Images with Metal Coating

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Abstract. The novel method of sub-nanometer uncertainty for the line width and line profile measurement using STEM (Scanning Transmission Electron Microscope) images is proposed to calibrate CD-SEM line width measurement. In accordance with the proposed method, the traceability and reference metrology of line width measurements are established using Si lattice structures. The interface of SiO_2-Air is defined using image intensity of STEM image after metal coating. The edge positions of the Si line from top to bottom are detected. Then, the pixel size of the images is evaluated using 2D Fourier analysis for Si lattice structures. Using the proposed method, the line profile and line width of 50 nm are measured with expanded uncertainty less than 0.3 nm.

Introduction

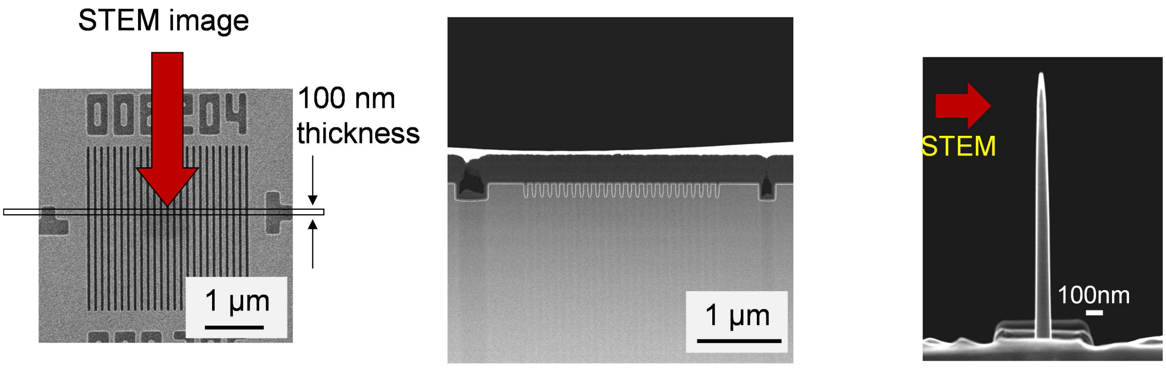
The line width measurement in semiconductor industry is mainly carried out by CD-SEM (Critical Dimension Scanning Electron Microscope). The sub-nanometer repeatability of the line width measurement can be obtained using CD-SEM [1-3]. However, absolute accuracy of line width and line profile measurement is not evaluated, and traceability is not established in the measurement [4-6]. The absolute accuracy of line width and line profile is recently in great demand for physical simulations such as spectrometry and performance evaluations of transistors. The requirements of the reference measuring method for CD-SEM, CD-AFM, OCD (Scatterometry) and physical simulations are the absolute measurement with sub-nanometer uncertainty for line width and line profile of Si line.

Therefore, we started to develop the novel method of the line width and line profile measurement with high absolute accuracy. In this article, the novel method of sub-nanometer accuracy for line width and line profile measurement using STEM (Scanning Transmission Electron Microscope) images is proposed to establish the reference measuring method for calibrating CD-SEM and CD-AFM line width measurements.

STEM image of the sample with metal coating

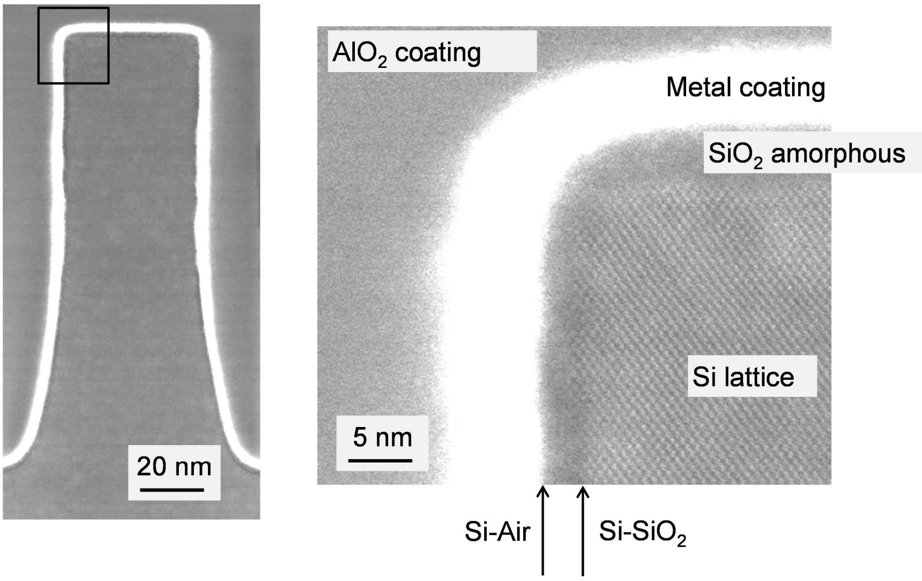
We use a standard Si line and space specimen, and the specimen is coated by metal and carbon. Fig. 1 illustrates the specimen that is sliced 100 nm of thickness on Si 110 surface by FIB (Focused Ion Beam) micro sampling system (FB-2100) [7]. Then, the STEM images of the specimen are obtained by STEM (HD-2700) [8] with accelerating voltage of 200 kV and magnification of 70,000 to 3,000,000.

Fig. 2 shows two interfaces of Si-SiO_2 and SiO_2-Air. Si-SiO_2 interface is surface between Si lattice structure and amorphous structure of SiO_2. We confirmed the method to detect the Si-SiO_2 interface in previous studies [9,10]. And SiO_2-Air interface is surface between SiO_2 and outside of Si line. The SiO_2-Air interface is detected using differences of image intensity between SiO_2 and metal after metal coating on the outside of Si line.



(a) (b) (c)

Figure 1. Sample for STEM image; (a) position of a thin specimen of 100 nm thickness by FIB (Focused Ion Beam) micro sampling system in the CD-SEM image, (b) STEM image of standard line width in low magnification, and (c) thin specimen of 100 nm.



(a) (b)

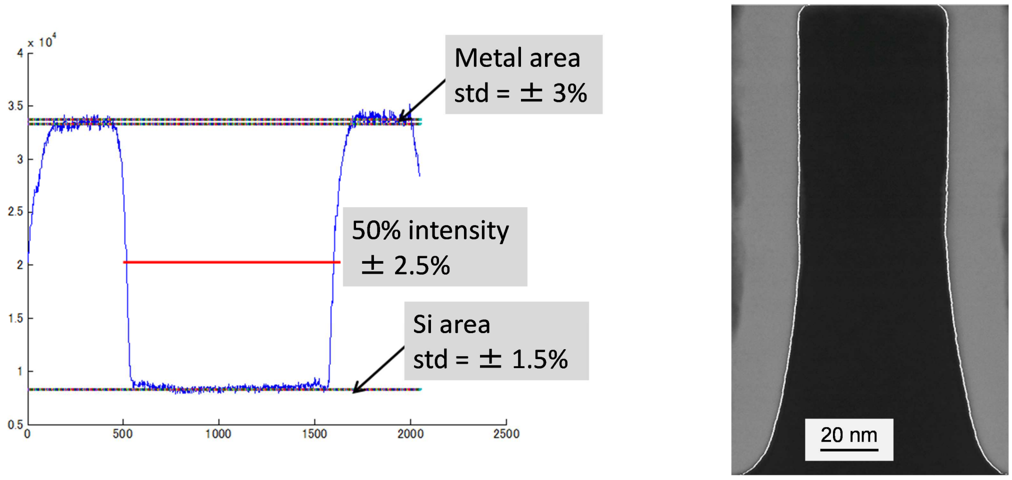
Figure 2. Si lattice structures and two interfaces (Si-SiO_2 and SiO_2-Air) are observed by a STEM dark field image of the thin spacemen with metal coating; (a) STEM dark field image, and (b) Si lattice, SiO_2 amorphous and metal coating in the high magnification image.

Line edge detection for SiO_2-Air surface and pixel size calculation

Fig. 3 (a) shows the data processing of edge detection from an image intensity graph. First, average values in the metal area and the Si area are calculated, and then 50% threshold level is calculated. Using the threshold level, left and right positions of the edges are detected. The edges of the Si line from top to bottom are detected shown in Fig. 3 (b).

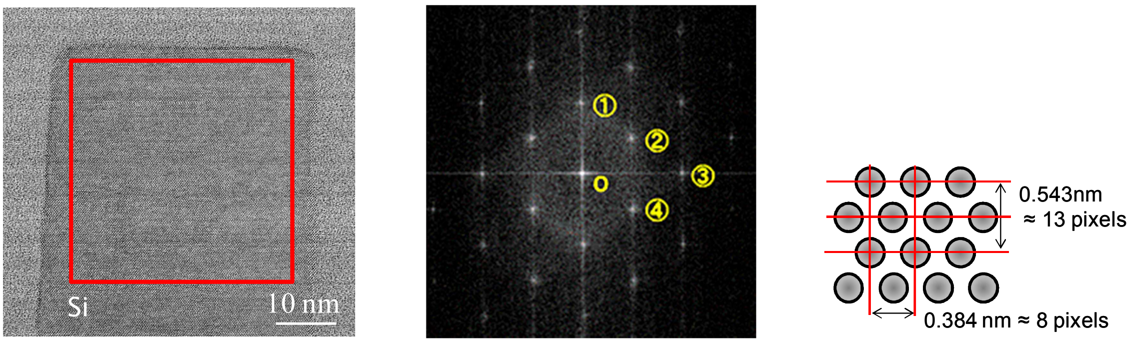
Si lattice structure is observed clearly on the high magnification STEM images. A pixel size of the image is calculated using 2D Fourier analysis. Fig. 4 (a) is an example of STEM image. The inside of Si lattice is extracted and transformed to a frequency domain image (Fig. 4 (b)) with zero padding method. The positions of peaks of the frequency domain image are compared with the Si lattice structures (Fig. 4 (c)), then, the image pixel is calculated. The pixel size of the image (Fig. 3 (b)) is calculated as 0.04708 nm/pixel.

The line width on each position is calculated using the left and right edge position and the pixel size. For example, the line width for Fig. 3 (a) is evaluated as 50.989 nm.



(a) (b)

Figure 3. Definition of the edge as the SiO_2-Air interface; (a) intensity graph of the STEM dark field image, and (b) edge detections from top to bottom.



(a) (b) (c)

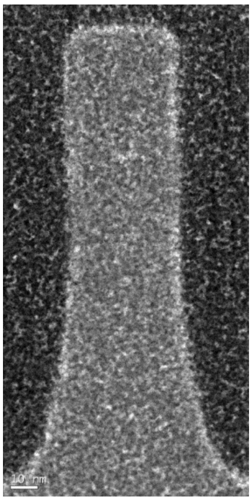
Figure 4. 2D Fourier analysis of STEM image; (a) inside of Si lattice is extracted, (b) transformed to a frequency domain image with zero padding and four main peaks, and (c) Si lattice structure.

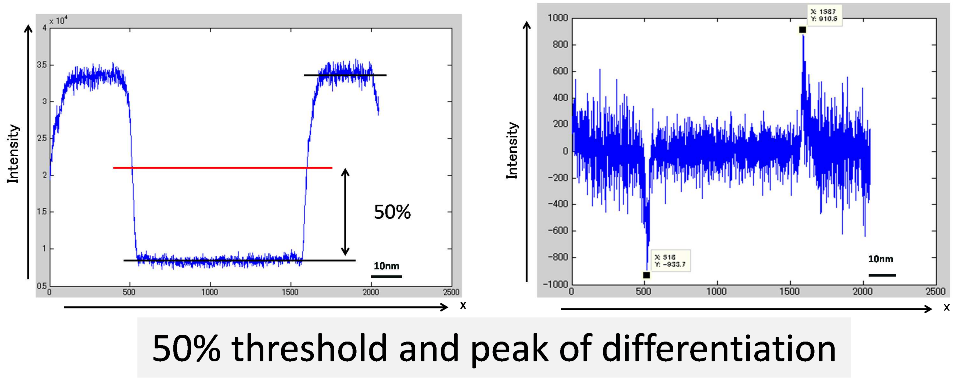
Conclusions and future works

The novel method of sub-nanometer accuracy for the line width and line profile measurement using STEM images is proposed to calibrate of CD-SEM line width measurement. In the proposed method, the traceability and reference metrology of line width standards are established using Si lattice structures. Using STEM images, the line width is calculated the following procedure:

- We define two types of interface of Si-SiO_2 and SiO_2-Air.
- The specimen is coated by metal and carbon, then, it is sliced 100 nm thickness on Si 110 surface by FIB (Focused Ion Beam) micro sampling system.
- STEM images of the specimen are obtained by STEM (HD-2700).
- The pixel size of the STEM image is calculated by the peeks of the frequency domain image using 2D Fourier analysis.
- The edge positions of SiO_2-Air interface are detected at the 50% intensity of the image intensity graph of STEM image after metal coating.

The proposed method was applied to an example of Si line specimen, and the line width is calculated with the estimated accuracy less than 0.3 nm. In future works, we will use sectional SEM images shown in Fig. 5 (a) and compare the line width by 50% threshold level and peak of differentiation shown in Fig. 5 (b). Then the detailed estimation of the uncertainty of the proposed method is calculated for establishment of the traceability.





(a) (b)

Figure 5. Future works; (a) sectional SEM images, and (b) comparison between the line width by 50% threshold level and peak of differentiation.

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