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Three-Dimensional Observation of Edge-Roughness on Poly-Si/TiN Stacked Gate Using Three-Dimensional STEM

S. Ono*, M. Yamane**, A. Katakami*, J. Yugami*, M. Koguchi**, M. Ogasawara***, M. Miyakawa***, H. Kakibayashi*** and Y. Ohji*

*Semiconductor Leading Edge Technologies (Selete), 16-1 Onogawa, Tsukuba, Ibaraki 305-8569, Japan
**Central Research Laboratory, Hitachi, 1-280 Higashi-koigakubo, Kokubunji, Tokyo 185-8601, Japan
***Hitachi High-Technologies Corporation, 1-24-14 Nishi-shimbashi, Minato-ku, Tokyo 105-8717, Japan

As semiconductor devices shrink in size, it has become important to control device structure. According to the 2007 ITRS requirements, for example, an etched line width roughness (LWR) of 1.4 nm and lower is required for lithography before the year 2010. In order to control the devices with such high precision, a device observation method with nanometer-scale precision is indispensable. For this purpose, we performed three-dimensional STEM (3D-STEM) observations on poly-Si/TiN stacked gates, to measure edge-roughness of the gate sidewalls.

For the 3D-STEM, the gate needed to be covered with a thin layer, such as carbon, to protect it from radiation damage from a focused ion beam (FIB). However, the image contrast between poly-Si and carbon was insufficient. Using the atomic layer deposition (ALD) method, we formed a thin film containing a heavy metal (replica layer) on the gate before coating it with carbon. A cross-sectional dark-field STEM image showed that the replica layer permitted visualization of the gate surface (Fig. 1).

We prepared a pillar-shaped specimen using an FIB (FB-2100, Hitachi), acquired various STEM images using a 3D analysis holder and a STEM equipped with a Schottky electron gun (HD-2300, Hitachi), and obtained 3D-reconstructed images. In order to acquire peak-profile of the replica layer, as illustrated in Fig. 2, we extracted edge-profiles of the inside and outside edges of the replica layer, and averaged them. Figure 3 shows the peak-profiles obtained from the projection images of the 3D-reconstructed image, along with those obtained from original STEM images (2D-STEM). The obtained peak-profiles were in good agreement; the difference in the peak-profile position was less than 1 nm, as shown in Fig. 3. Thus we consider that the 3D image processing did not affect for extracting the peak-profile of the replica layer.

Then, using the peak-profiles obtained, we acquired a 3D profile of the stacked gate by subtracting the thickness of the replica layer, bearing in mind that the replica layer represented the gate surfaces. After that, we calculated edge-roughness of the stacked gate. Figure 4 (a) shows the z-axis dependence of line edge roughness (LER). The LER increased at the gate top and decreased at the poly-Si/TiN interface, suggesting the sidewall was less uniform at the top, and was more uniform at the interface, which may result from fabrication process. Figure 4 (b) shows the z-axis dependence of gate length (CD). The CD decreased at the gate top and increased at the TiN layer. The average of the CD distribution measured by this 3D-STEM was similar to the CD measured by the CD-SEM (31.4 nm). Figure 4 (c) shows the z-axis dependence of LWR. The LWR on TiN was smaller than that on poly-Si, suggesting the edge-roughness varied depending on the z-axis position and the material that composed the gate. The average of the LWR measured by this 3D-STEM was also similar to that measured by the CD-SEM (6.2 nm). The averages of the CD and LWR obtained from the 3D-STEM measurements were in good agreement with those obtained from CD-SEM.

References
[1] M. Koguchi, et al., Journal of Electron Microscopy 50, 235 (2001).
[2] T. Ohnishi, et al., 25th Int. Symp. for Testing and Failure Analysis, 449 (1999).
[3] T. Yaguchi, et al., 29th Int. Symp. for Testing and Failure Analysis, 282 (2003).

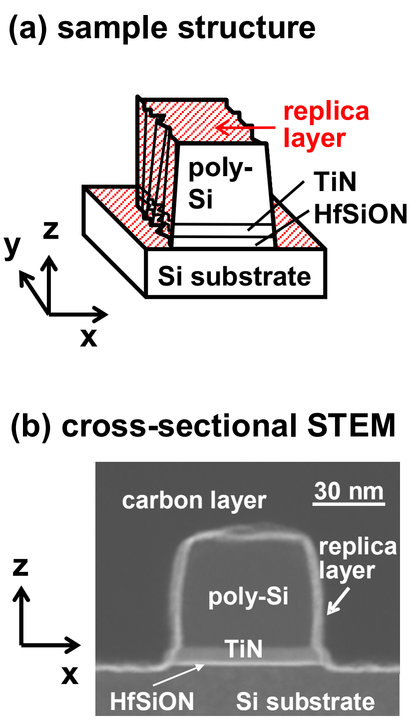


Fig. 1: (a) Schematic drawing and (b) cross-sectional STEM image of the poly-Si gate coated with replica layer and carbon. The replica layer visualized the gate surface.

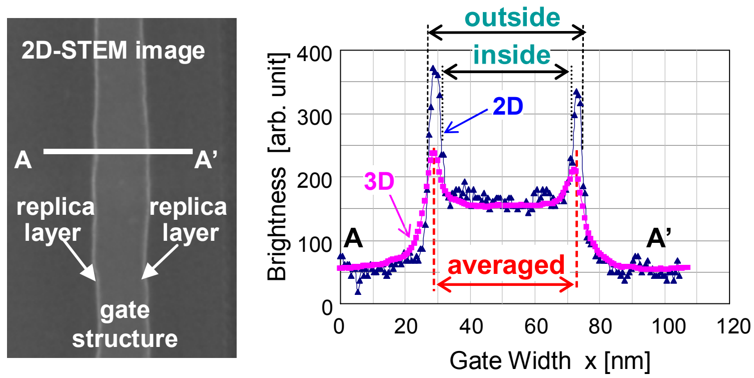
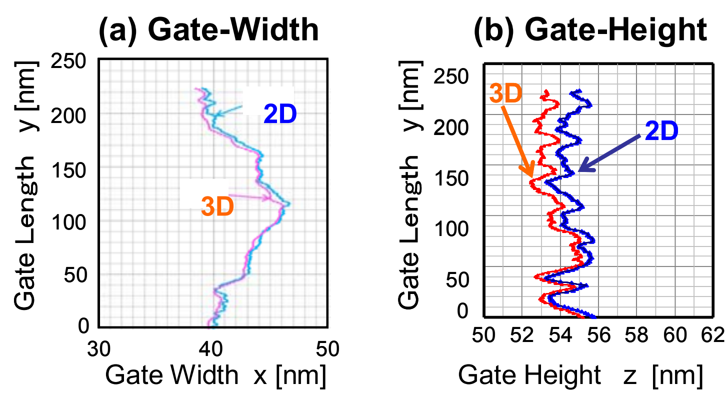


Fig. 2: (a) Original STEM image and (b) peak-profile extraction method. We extracted edge-profiles inside and outside of the replica layer, and averaged them.



2D AVR.	3D AVR.	2D-3D AVR.
42.6 nm	42.3 nm	0.4 nm

2D AVR.	3D AVR.	2D-3D AVR.
54.5 nm	53.6 nm	0.9 nm

Fig. 3: Profiles of (a) gate-width (CD) and (b) gate-height obtained by the 3D- and 2D-STEM images.

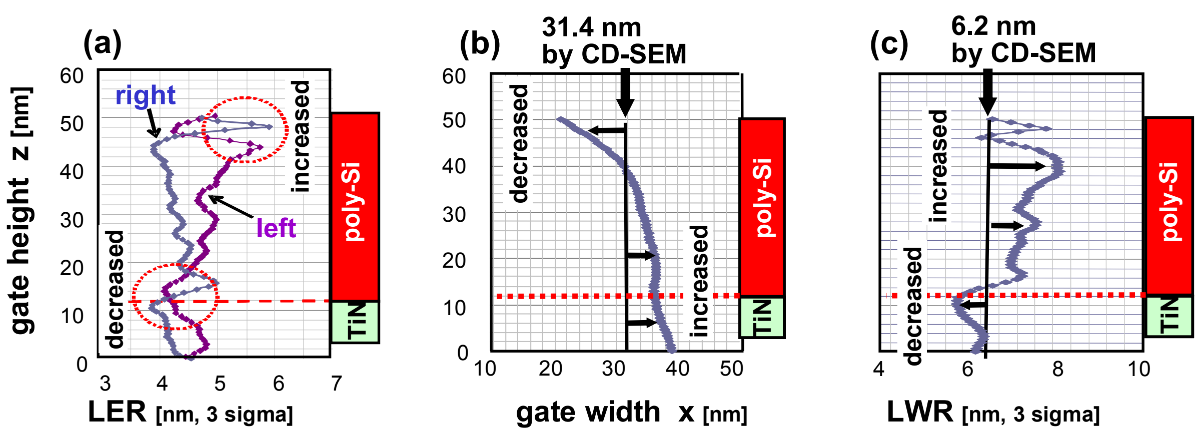


Fig. 4: Z-axis position distribution of (a) LER, (b) gate width (CD) and (c) LWR. Average of CD and LWR were in good agreement to those obtained by CD-SEM.

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