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Strain Analysis of FinFET Device Utilizing Moiré Fringes in Scanning Transmission Electron Microscopy

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In semiconductor industry, the progressing miniaturization makes the device structure to be three dimensional (3D). A typical 3D structure for a field effect transistor (FET), which is used for highly integrated devices, is a finFET, which has a tri-gate structure [1]. On the other hand, for the less power consumption and higher switching speed, the device technology utilizes strained silicon to enhance the mobility of carriers. In the case of a typical pMOS device, the strain arises between the stressors typically consisting of Si/Ge. It is important to measure of the strain of the channel in finFET. However, it was difficult to measure, since the channel is sandwiched with gates (see Fig. 1). And the sample thickness cannot be as thin as < 100 nm to avoid strain release [2]. On the other hand, we have succeeded to measure a strain by moiré fringes, which appears as a result of undersampling lattice fringes in the raster of scanning transmission electron microscopy (STEM), we namely call the method "STEM moiré" [3, 4, 5]. We applied the method to measure the strain of Si channel in a finFET. In this paper, we report how we measure the strain by the STEM moiré method.

The measurement was performed with an aberration corrected microscope (JEM-ARM200F, JEOL) equipped with cold field emission gun to enhance the contrast of the moiré fringe. The sample was made by focused ion beam (FIB) to be as thin as 150 nm, which was confirmed with 3D tomography and EELS measurement. Therefore, the volume of the sample includes three fins. The lamella was cut along the X direction (channel direction) so that we can observe the strained channel between Si/Ge stressors. The moiré fringe we used was formed by Si [220] reflection. The moiré method extracts only the target lattice in the Si channel, since it works as a real space frequency filter.

Figure 2 (a) shows the bright field (BF) STEM image of the X-cut sample observed at 200 kV. The black area is overlapped with the W electrode, and the grey area might have a double-layer stacked structure of a gate electrode of TiN_x and an insulator of SiO_xN_y. These composing elements were confirmed with 3D elemental volume map reconstructed by 3D EDS (energy dispersive X-ray spectroscopy) tomography. We could not observe the moiré fringe under the W electrode, since it absorbs and/or scatters electrons too much. Therefore, we measured the strain from the area around the W wire, which is not overlapped with the W electrode. Figure 2(b) shows the measured strain map of the sample. The strain shown in the map is of [220] lattice, which is ε_{xx}. Therefore, the direction of the strain is along x direction. The line profile was shown in Fig. 2(c). the area sampled for the profile is indicated by yellow rectangle in Fig. 2(b). Finally, the compressive strain ε_{xx} of the channel between Si/Ge stressors was successfully measured to be - 0.7 - 0.8%.

In conclusion, the STEM moiré method can be applicable to strain analysis of 3D device such as finFET, since the STEM moiré fringes act as a real space spatial filter and can extract only the lattice of Si channel. This advantage of the method can generally be applied to measure the strain of the target volume surrounded by other materials.

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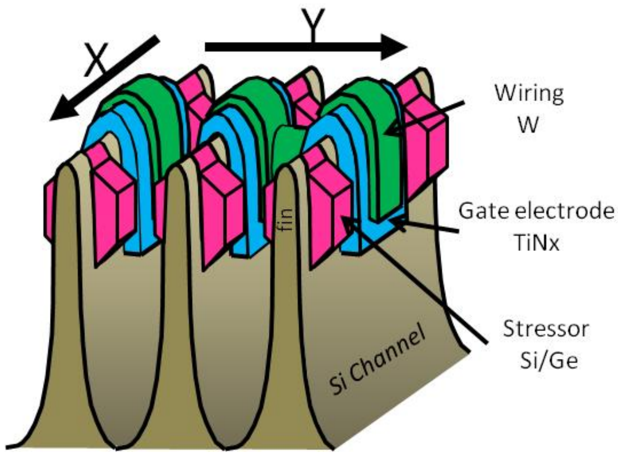

Figure 1. Scheme of typical finFET structure.

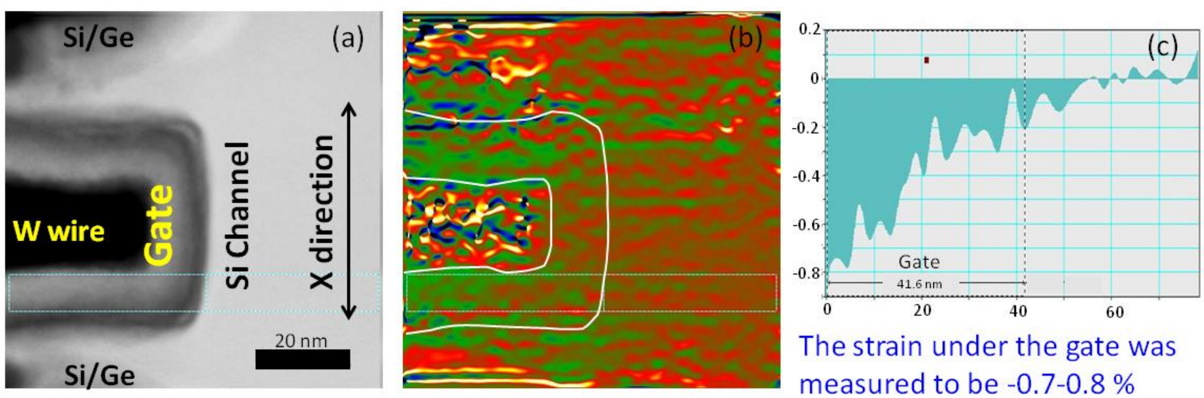

Figure 2. Results of strain analysis by STEM moiré method using JEM-ARM200F at 200 kV. a) X-cut view of a finFET device. The gate and W wire overlap the Si channel. b) Strain (ε_{xx}) map of the device. c) profile of strain map shown in (b).

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