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Strain measurement of semiconductor device by moiré fringes in STEM

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In scanning transmission electron microscopy (STEM), when the spacing for an STEM raster is similar to one for a crystal lattice or the multiple of it and the probe size is smaller than the crystal lattice spacing, the moiré fringes appears due to under-sampling effect. Since we can arbitrarily select the raster spacing and the rotation angle of the raster direction unlike a TEM moiré method [1-3], we can intentionally make the moiré fringes with wider spacing than crystal lattice that is wide enough to be visible even at lower magnification. The moiré fringe bends in strained region in a crystal. And the lattice strain can be measured by the curvature of the fringe, because the spacing and direction of the moiré fringe can be definitely expected by geometrical calculation. D. Su and Y. Zhu observed of a dislocation in a crystal that generates with very large strain, utilizing the STEM moiré fringes method [4]. However, the detection of a small strain, which is utilized for a strained silicon device, has been remained untouched. It is important to measure the strain in strained silicon device, because the device has high speed mobility of electrons, resulting in high processing speed. In this paper, we report the results of the method to detect and quantify the small strain in the practical silicon device over the region wide enough for the device characterization.

The sample and the microscope we used were a 150-nm-thick FIB-made semiconductor device and JEM-ARM200F. Figure 1 (a) and (b) shows HAADF images of the device around Si-Ge mixed crystal regions, showing parallel moiré fringes generated with the raster and the lattice fringes due to Si (220) reflection. Figure 1 (a) includes the strained region under the gate of device located between Si-Ge regions. The fringes bend rapidly just under the gate of the device, which implies that the region under the gate is strongly strained. Around Si-Ge crystal, the fringes gradually bend, which tells us that the strain occur not only the region under the gate, but wider region of the device around the Si-Ge crystal. The non-strained region located right of each image shows straight moiré fringes, because the region does not contain strain. Thus, the moiré fringes allow us to grasp the distribution of the strain.

To measure the curvature of the fringe, we utilize the phase analysis method of holography, which is similar to the way in high resolution transmission electron image [5]. The phase map is reproducible from the moiré fringes (carrier fringes), the result of phase analysis shows amount of lattice displacement which is the integrated strain map. The derivative of the integrated strain map shows the map of strain. In our experiment, the integrated strain of the lattice fringe almost parallel to the horizontal scanning raster. Therefore, the strain map reproduces in the vertically differentiated integrated strain map. Figure 2 (a) shows the HAADF image of silicon device showing the tilted moiré fringes. These moiré fringes are rotation moiré fringes caused in scanning raster and the l attice fringes due to Si [111]. The raw strain map affected by slow and slight displacement of the sample during image acquisition, since the acquisition time is rather long. To reduce the affection, the right quarter region was used as a reference, because the region does not have strain. The accurate strain map can be obtained by the subtraction of raw map by the map of reference region. In Fig. 2(b) and 2(c), a reproduced and subtracted integrated strain and strain maps are shown. Amount of strain under the gate was measure as 1.9 % from the strain map shown in Fig. 2(c).

To measure the amount of noise for this method, we performed a blank test on the non strained single crystal of silicon with the same manner. The HAADF image showing moiré fringes is shown in right region of Fig. 3 and the strain map is shown in left panel. The standard deviation of the strain was measured to be ± 0.2 % at present stage. However, the accuracy might be improved with better contrast of moiré fringes and less noise by further improvement of this technique. In conclusion, the strain distribution of a crystal can be reproduced from only a medium magnification STEM image serving a wide field which is striking for strained device characterization.

1. G. A. Bassett, J. W. Menter and D. W. Pashley, *Proc. R. Soc. Lond. A 19* (1958) 246, 1246, 345-368.
2. Goro Honjo and Katsumichi Yagi, *J. Vac. Sci. Tech.* (1969) , 6 , 4, 576 – 582.
3. D W Pashley, M J Stowell, M H Jacobs and T J Law, *Phil. Mag.* (1964), 10, 127-158.
4. Dong Su and Yimei Zhu, *Ultramicroscopy* (2010), 110(3), 229-233.
5. M.J. Hÿtch, E. Snoeck and R. Kilaas, *Ultramicroscopy* (1998), 74, 3, Pages 131–146.

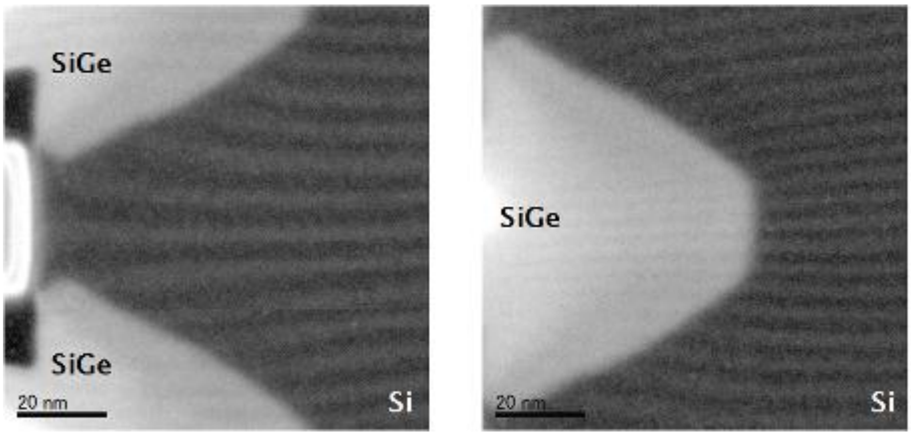

Figure 1. STEM moiré fringes of Si substrate under the gate (a) and Si-Ge crystal (b).

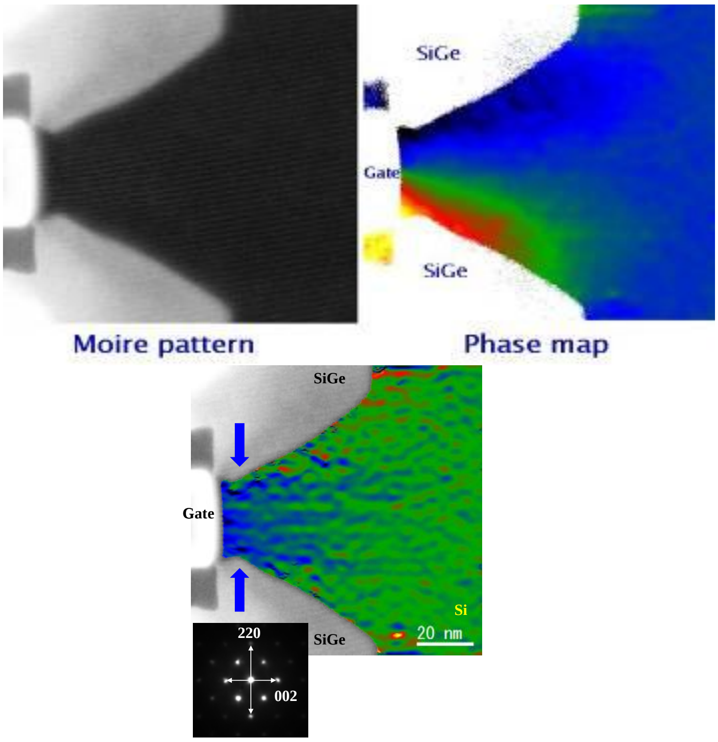

Figure 2. (a) HAADF image of moiré fringes (b) Phase map of moiré fringes (c) Strain map of strained silicon device.

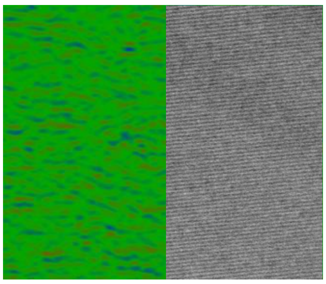

Figure 3. (a) Strain map reconstructed STEM from Fig. 3 (b), (b) moiré fringes of Si single crystal without strain.