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Holographic Phase Imaging of Charged Threading Dislocations in 4H-SiC

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Electron holography is an interferometric technique that can measure with nanometer-scale resolution the phase shift of an electron wave passing through a specimen [1]. The technique is capable of map out local variations in electrostatic potential associated with defects or junctions [2]. Since performance of SiC-based devices is affected by presence of threading dislocations [3], it is important to assess the trap and the charge density associated with the dislocation core. This information was obtained by off-axis electron holography.

The samples studied were prepared from 4H-SiC wafer with 20-um-thick n-doped ($N_d=3.3\text{x}10^{16}\ \text{cm}^{-3}$) 4H-SiC epilayer. As-grown epilayer was etched in molten KOH for 3 minutes at 500 ℃. According to typical etch-pit of threading dislocations, threading screw dislocation was selected and cross-section TEM sample was then prepared by using focused ion beam (FIB). After holography window was cut for vacuum proximity, final thinning was done with low energy ion beam (5 kV and 10 pA) in order to minimize the thickness of electrically inactive layer caused by FIB. Holograms were taken at minimum diffracting condition, ensuring measured phase shift results from only potential variation.

Figure 1(a) is bright-field image showing the etch pit, the threading dislocation line and holography window. Figure 1(b) schematically shows the cross section of the TEM foil with desirable location of the dislocation. Holograms were taken at position indicated by the white box in Fig. 1(a), so that whole depletion cylinder of the dislocation is located inside the TEM foil. Reconstructed phase image in Fig. 2(a) shows darker contrast along the dislocation, suggesting lower potential. Increase in phase from bottom to top is attributed to increasing foil thickness. Diameter of the depletion region was determined, based on the corresponding phase profile (not shown here), to be 120 nm. This value was also used as an effective thickness due to the fact that only the depletion region contributes to phase change. Electrostatic potential was then extracted from both phase and thickness information, and the result is shown in Fig. 2(b). Expected potential drop near the negatively charged dislocation in Fig. 2(b) was simulated using Read cylinder model [4]. Comparison between experimental and simulated potentials provided the charge density of 0.38±0.03 electrons/c ($=5.4\text{x}10^{19}\ \text{cm}^{-3}$) where c of 1 nm is the unit cell parameter. Measured charge density is comparable to those in GaN and ZnO [5]. The experimental potential could be underestimated due to the presence of the dead layer [6]. However, it has been reported that the dead layer thickness for the TEM sample prepared by FIB with 5 kV final cleaning is 20 nm each for top and bottom surfaces [7]. Therefore, our measurement was not significantly affected by the dead layer, as shown in Fig. 1(b).

References

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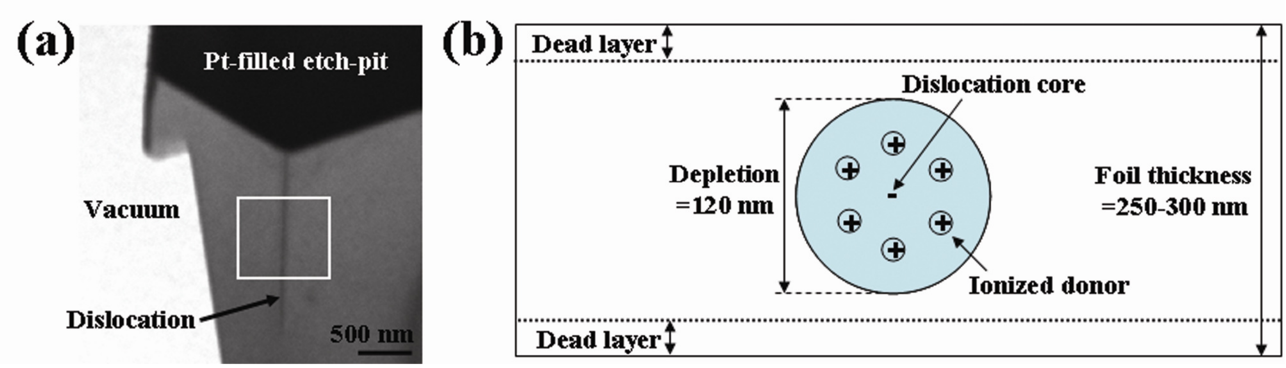

FIG. 1. (a) Bright-field image; (b) Schematic drawing of cross-section showing desirable location of dislocation in TEM foil. Foil thickness was estimated from normalized amplitude image, assuming inelastic mean-free-path value of 93 nm for 4H-SiC.

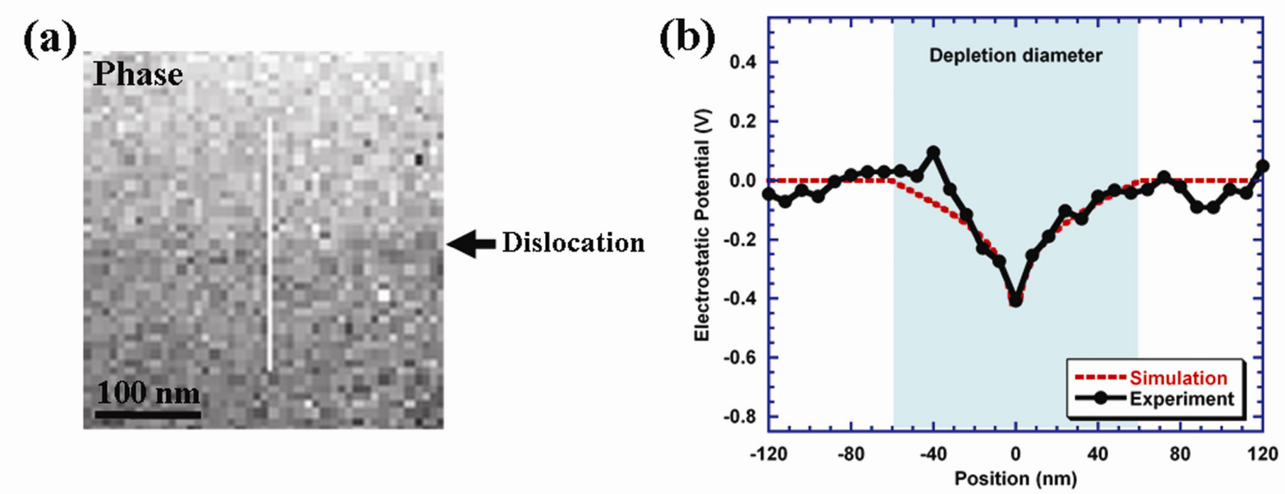

FIG. 2. (a) Reconstructed phase image; (b) Experimental potential profile from line indicated in (a) and simulated potential. Line profile was averaged over 15 pixels to improve signal to noise ratio.