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Site Specific TEM Specimen Preparation for Characterization of Extended Defects in 4H-SiC Epilayers

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Silicon carbide (SiC) is an important semiconductor for high temperature, high voltage and high power electronic applications. Unfortunately, SiC still has not reached its potential in these applications due to the presence of extended defects in epilayers, which degrade the performance of SiC-based devices. In this work, focused ion beam (FIB) is employed to prepare site-specific cross-sectional transmission electron microscopy (TEM) specimens allowing direct characterization of unwanted in-grown stacking faults (IGSFs) and basal plane dislocations (BPDs). IGSFs are known to decrease breakdown voltages and increase leakage currents in SiC diodes [1]; however, their nucleation mechanism is currently not established. BPDs can form recombination-induced stacking faults, which lead to device performance degradation over time [2]. Recently, KOH etching of the substrate was reported to cause conversion of BPDs to electrically benign threading edge dislocations (TEDs) in the epilayer. However, for some BPDs this conversion was also associated with a shift in the locations of etch pits [3]. In this study, FIB and TEM are used to explain the nucleation mechanism of IGSFs and the previously observed shift in the locations of BPDs.

4H-SiC epilayer samples were grown by chemical vapor deposition (CVD) on 4° off-cut 4H-SiC (0001) substrates. The epilayers were etched by KOH to form pits at the emergence point of dislocations at the epilayer surface. The etch pits were used as a guide to prepare site-specific TEM specimens. The geometry of the pits guided the selected orientation of TEM specimens during FIB preparation, whereas the depth and profile of the pits are useful during FIB thinning of the TEM specimens.

Figure 1(a) shows a scanning electron microscopy (SEM) image of two etch pits bounding an IGSF on the surface of the epilayer. The upper etch pit is aligned along the $[11\bar{2}0]$ direction. The black rectangle denotes the location of the TEM specimen. Figure 1(b) shows a bright-field TEM micrograph of the specimen, where the etch pit also appears on the right side. During thinning of the specimen in the FIB, the depth of the etch pit is monitored from both sides of the specimen to ensure that the deepest point of the pit (the dislocation's emergence point) is captured in the TEM specimen. In Figure 1(b), the IGSF appears as a faint dark line extending from the etch pit. Based on TEM analysis, the IGSF nucleated homogenously in the epilayer with no observed defect or heterogeneity in the substrate or epilayer. Thus, we speculate that nucleation of IGSFs is mainly related to growth parameters that favor 2D nucleation of islands over step-flow growth.

Figure 2(a) shows a hexagonal etch pit at the emergence point of a BPD that converted to a TED. A TEM specimen was prepared in the FIB to perform **(g · b)** analysis. Figure 2(b-d) show bright-field TEM micrographs for a BPD that converted to TED with a shift in the location of the TED etch pit in the $[\bar{1}\bar{1}20]$ direction. The dislocation is invisible in $g_{000\bar{4}}$ and $g_{\bar{1}10\bar{8}}$ two-beam orientations, and the Burgers vector is along $[11\bar{2}0]$ (i.e. BPD is a screw dislocation). Figure 3 (a-d) show a similar analysis for a BPD that converted to TED with no shift. The Burgers vector is along $[2\bar{1}\bar{1}0]$. Based on this analysis, the shift of TED etch pits can be explained by glide of TEDs along the BPD line direction. This process is only possible and energetically favorable when the dislocation Burgers vector is along the BPD line direction. (i.e. BPD is a screw dislocation). Overall, the available control and precision by FIB-based TEM sample preparation allows such analysis of specific defects in crystalline solids.

References:

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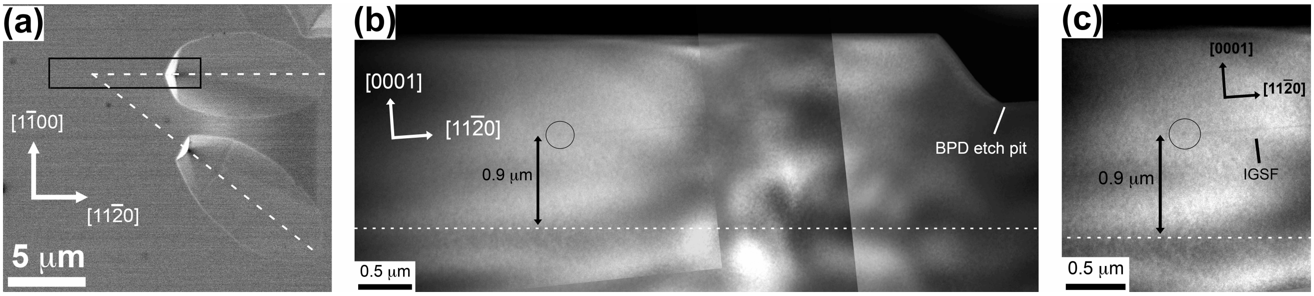

Figure 1. (a) SEM image of two etch pits bounding an IGSF demarcated by white dashed lines. ihe black rectangle shows the location of the TEM specimen. (b) Bright-field TEM micrograph at $[\bar{1}2\bar{1}0]$ zone-axis orientation showing nucleation of IGSF. The white dashed line represents substrate/epilayer interface. (c) Magnified TEM view of the IGSF nucleation shown in (b).

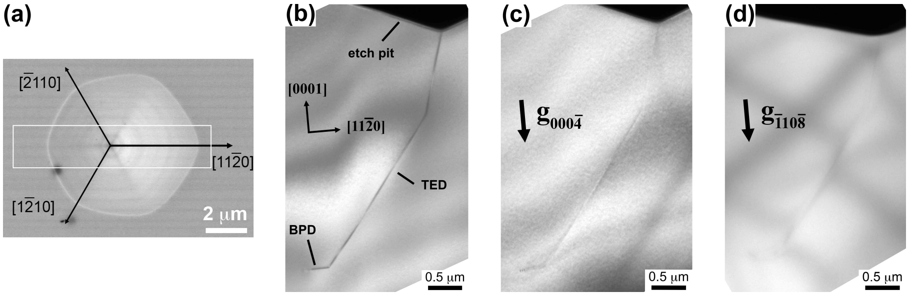

Figure 2. (a) SEM micrograph showing TED etch pit on epilayer surface. (b-d) Bright-field TEM micrographsat (b) $[1\bar{1}00]$ zone-axis, (c) $g_{000\bar{4}}$ two-beam and (d) $g_{\bar{1}10\bar{8}}$ two-beam orientations

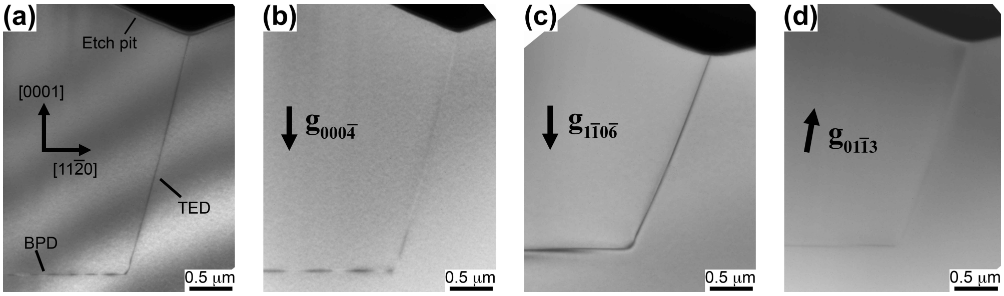

Figure 3. Bright-field TEM micrographs at (a) $[1\bar{1}00]$ zone-axis, (b) $g_{000\bar{4}}$ two-beam (c) $g_{1\bar{1}0\bar{6}}$ two-beam and (d) $g_{01\bar{1}3}$ two-beam orientations.