doi:10.1017/S1431927617003567
Microsc. Microanal. 23 (Suppl 1), 2017
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High-Contrast Visualization of Anti-Phase Domains and Screw Dislocations in 3C-SiC

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Silicon carbide (SiC) is an important wide bandgap semiconductor with many polytypes. 3C-SiC is the only cubic polytype, to be distinguished from the hexagonal polytypes such as 4H-SiC and 6H-SiC. Crystalline 3C-SiC, grown by heteroepitaxy, often contains twin structures, also called anti-phase domains (APDs), that are separated by double positioning boundaries (DPBs). This naturally occurs when growing 3C-SiC, since there are two possible and equally-likely stacking sequences with a relative in-plane rotation of 180 degrees as shown in Figure 1. The challenge faced when imaging these APDs, is that neither optical or scanning electron microscopy provides a clear contrast between the rotated domains, as they are composed of the same material with identical properties. This paper demonstrates high-contrast imaging of such APDs, enabled by channeling of electrons or ions.

Historically, defect characterization in crystalline materials has been performed with transmission electron microscopy (TEM), a technique, which has also been applied to the investigation of APDs in 3C-SiC [1]. However, this requires time-consuming preparation of TEM samples. An alternate approach, when studying APDs in 3C-SiC, is the use of electron backscatter diffraction (EBSD), which can provide orientation mapping on a smooth or polished surface [2, 3]. Electron channeling contrast imaging (ECCI) is yet another method that has successfully been used to identify screw dislocations in SiC [4]. ECCI is usually performed using a scanning electron microscope (SEM) equipped with a backscatter electron detector and/or forescattered electron detector. This technique has been adopted for the visualization of surface and subsurface defects in crystalline solids. It has also been reported that defects in crystals can be imaged with a standard secondary electron detector (SED) in the diffraction mode [5]. Additionally, crystallographic orientation contrast due to ion channeling has been widely observed in focused ion beam (FIB) systems [6]. In this paper, we report on contrast obtained by both incident electrons or gallium ions that channel through the crystalline materials, and dependent on orientation produce a different amount of secondary electrons that can be readily detected with an SED instead of a backscattered or forescattered electron/ion detector.

We applied channeling contrast imaging (CCI) techniques in order to evaluate the material properties of 3C-SiC grown by hot-filament chemical vapor deposition on a (0001) on-axis 6H-SiC substrate [7]. A standard SEM image is shown in Figure 2(a). The DPBs are clearly visible, but the two APDs are not distinguishable. The cross-sectional view of a DPB is shown in Figure 2(b). In this image, it is confirmed that the boundary is, in fact, a V-groove with an approximate angle of 46 degrees, relative to the plane of the substrate. When the sample is tilted and rotated such that channeling is favored for one of the APDs, we are able to observe the domains with clearly different contrast, as shown in Figure 3(a). When the sample is slightly more tilted, the contrast between APDs reverses, as shown in Figure 3(b). This effect is even more pronounced when using a 30 kV gallium ion beam, as illustrated in Figure 4(a). The high contrast allows for an accurate determination of the relative coverage of each APD orientation.

https://doi.org/10.1017/S1431927617003567 Published online by Cambridge University Press

For the highlighted region in Figure 4(a), the ratio is 9 to 1. Furthermore, we discovered that the indirect ion channeling contrast imaging (ICCI) makes it possible to detect the screw dislocations in 3C-SiC without difficulty, as shown in Figure 4(b).

Conclusion: We demonstrated the use of CCI techniques to investigate crystallographic properties of 3C-SiC. In particular, indirect ICCI is capable of visualizing APDs with opposite orientation and screw dislocations in 3C-SiC grown on on-axis (0001) 6H-SiC.

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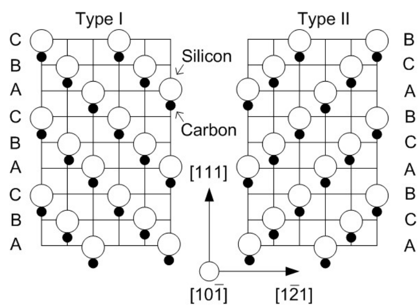

Figure 1. Two possible arrangements of Si and C atoms along the [111] direction for 3C-SiC polytype.

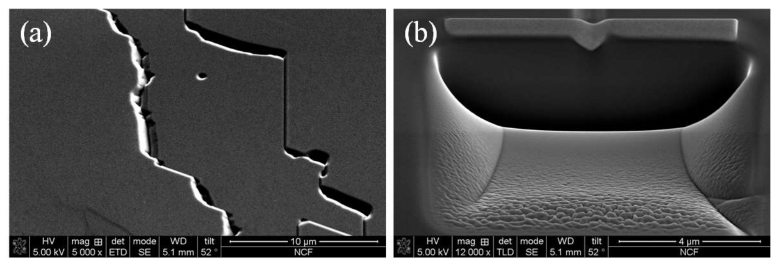

Figure 2. Standard SEM images of 3C-SiC. (a) top view, (b) cross-sectional view.

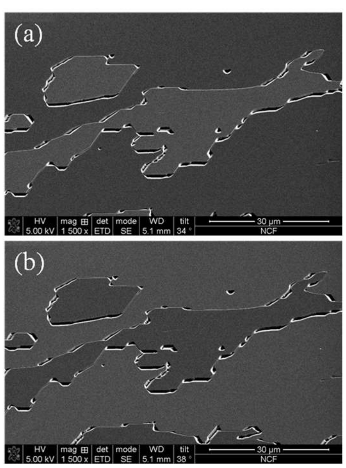

Figure 3. ECCI of 3C-SiC (5 kV, 98 pA). Images (a) and (b) were taken at slightly different diffraction conditions.

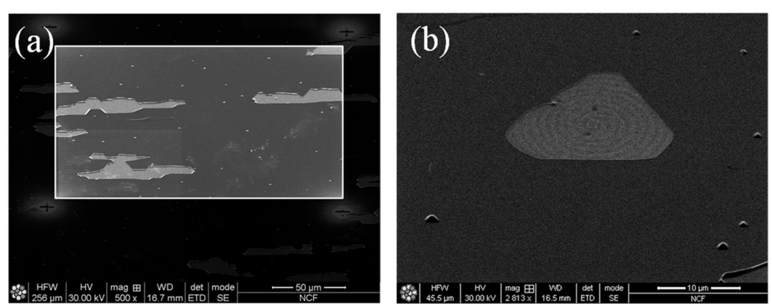

Figure 4. ICCI of 3C-SiC (30 kV). (a) with the APDs, (b) screw dislocation.