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## Material Defects in 4H-Silicon Carbide Diodes

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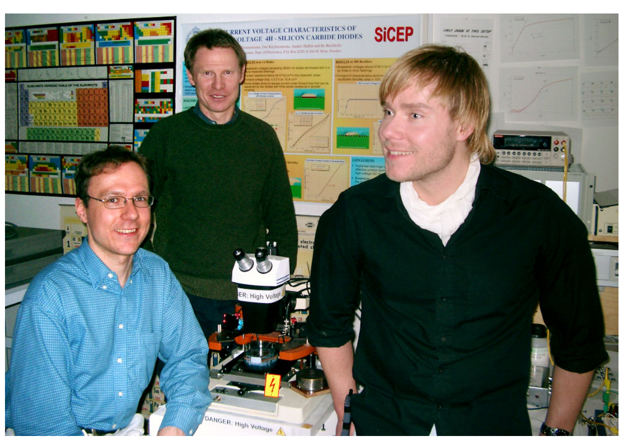
*The role of crystallographic defects on the performance of semiconductor devices has been studied using the example of pn junction diodes in the modern semiconductor compound silicon carbide. The correlation of the locations of crystallographic defects as observed by the Synchrotron White-beam X ray Diffraction Topography technique and the electrical characteristics of the electronic devices allows us to draw conclusions about the importance of high-quality semiconductor material for reliable device operation.*

The operation of all semiconductor components is based on the regular arrangement of atoms in the crystal lattice of the underlying material. Deviations from this regular arrangement can be introduced intentionally in the from of strained layers, compositional variations and impurity atoms in order to control and modify the electrical properties of the semiconductor material. However, this requires a base material of high purity and high crystalline quality.

Silicon carbide was discovered by the Swedish scientist Jöns Jakob Berzelius in 1824. Silicon carbide has long been used as an abrasive material only, even though its semiconducting properties had already been discovered in the beginning of the twentieth century. During the last decade, a new interest in silicon carbide was driven by its unique properties, which make this material a promising candidate for high-voltage, high power and high temperature electronics.

The growth of large crystals of silicon carbide for device fabrication has long been hindered by the tendency of the material to form different crystal lattices with different properties. These so-called polytypes are all built up by the stacking of bi-atomic silicon-carbon layers. Of technological interest are mainly the hexagonal crystals, 4H and 6H, and the cubic 3C variant. Although the technique of large crystal growth is under control nowadays, there still exists a diversity of crystallographic defects in state-of-the-art silicon carbide wafers. Of these defects, edge and screw dislocations are the most abundant ones. Figure 1 shows a model of a screw dislocation in the 4H polytype of silicon carbide.




*Authors (from left) Uwe Zimmermann, Anders Hallén and John Österman at the electrical measurement setup in Stockholm, Sweden.*

In our experiments, the location of screw dislocations on samples containing pn junction diodes was determined by the technique of Synchrotron White-beam X-ray Diffraction Topography, performed at the Synchrotron Topography Facility, Beamline X19C, at the NSLS. This technique delivered a two-dimensional map representing the crystalline structure of the sample, as shown in Figure 2. The data were then compared to electrical and electro-optical measurements on the individual diodes. The results showed a clear correlation between the presence of crystallographic defects and a reduced performance of the affected diodes.

The direct comparison between the light emission of the silicon carbide junction under reverse bias, the X-ray topograph, and the pictorial data of an electron-beam induced current (EBIC) measurement can be seen in Figure 3. While the electroluminescence under reverse bias shows inhomogeneities in the leakage current distribution (Figure 3a), the focused electron beam of a scanning electron microscope was used to generate electron-hole pairs adjacent to the junction in the EBIC measurement, which can be measured as an external current through the diode (Figure 3c). It is obvious that the electrical characteristics of the diode are affected by the presence of screw dislocations, as revealed in Figure 3b.

The presence of screw dislocations, where silicon carbide can have a hollow or a closed core, was found to have a dramatic influence on the critical electric field strength of the silicon carbide material. The critical electric field, which is ten times higher in silicon carbide as compared to silicon, allows a semiconductor diode to block high reverse voltages. A local reduction of this parameter inside the active area can lead to a catastrophic failure of the whole device. This study furthermore demonstrates that Synchrotron White-beam X-ray topography is a non-destructive technique suitable to locate these defects without the need for extensive sample preparation.

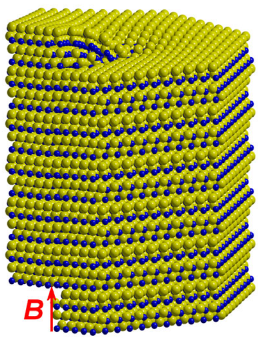



***Figure 1****. Schematic representation of a closed-core screw dislocation in the 4H silicon carbide polytype. The crystal planes are wound in a spiral around the dislocation line in the center. The step height is characterized by the magnitude of the Burgers vector B (red arrow).*

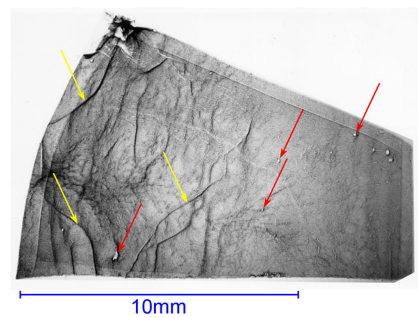



***Figure 2****. Synchrotron White-beam X-ray Diffraction Topograph of an investigated silicon carbide sample. In this magnification, the outlines of the individual diodes cannot be distinguished. However, grain boundaries (yellow arrows) and open-core screw dislocations ("micropipes", red arrows) can easily be seen.*

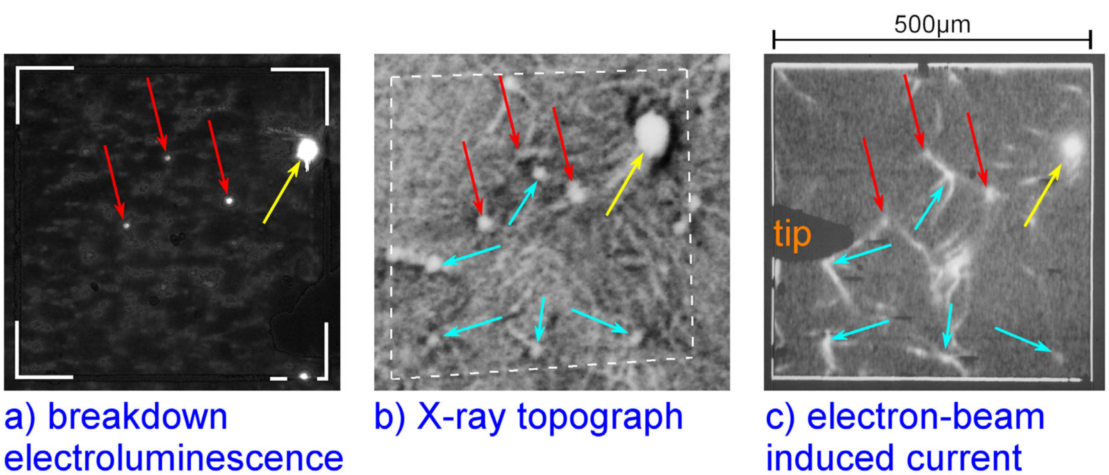



***Figure 3****. The breakdown luminescence (a) marks weak spots in the reverse biased pn diode, where the reverse leakage current is concentrated. The location of these spots correlates to the position of closed-core (red arrows) and open-core (yellow arrow) screw dislocations as seen on the X-ray topograph (b). However, not all screw dislocations seen on the X-ray topograph and by the electron-beam induced current technique (c) necessarily lead to electrical breakdown (cyan arrows).*