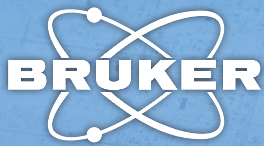

Application Note
#5200

Optimizing Ion Implantation Processes and 4H-SiC Wafer Performance Through Precise Offcut Measurements Using High-Resolution X-ray Diffraction

Silicon carbide (SiC) is a wide-bandgap semiconductor material with numerous applications in high-power, high-temperature, and high-frequency electronic devices. 4H-SiC substrates offer unique properties such as high thermal conductivity, high breakdown voltage, and excellent chemical inertness, making them ideal for power electronics, RF devices, and sensors. Ion implantation is a critical process in SiC device fabrication (Figure 1). This key step relies heavily on precise control over dopant distribution, meaning that accurate characterization of the wafer offcut or miscut angle is essential for achieving high device performance and reliability. Bruker's QCVelox high-resolution X-ray diffraction (HRXRD) system is a powerful tool to accurately determine the offcut angle, thereby optimizing the ion implantation process for 4H-SiC substrates.

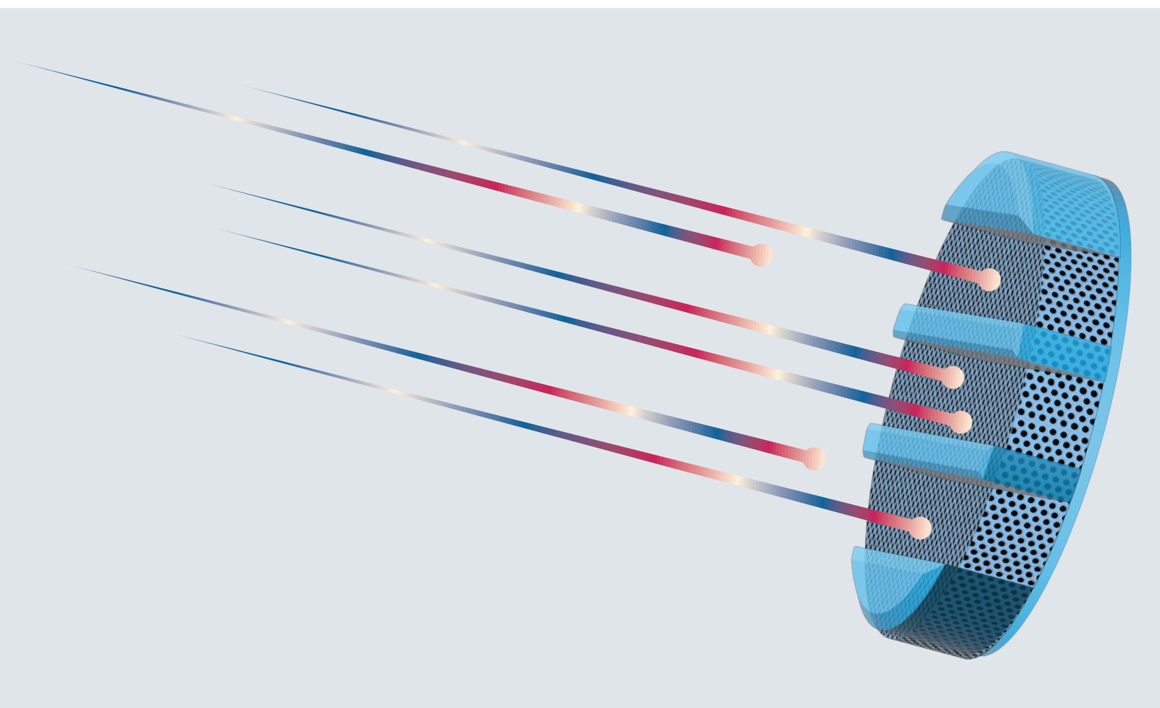

FIGURE 1.

Representation of the ion implantation process on SiC power device.

Importance of Accurate Offcut Angle in 4H-SiC in Ion Implantation

The offcut angle of a 4H-SiC substrate plays a critical role in determining the quality and performance of SiC devices. It is well known that defects in SiC are oriented parallel to the growth direction. As a result, an intentional offcut is imparted on SiC substrates to preserve the underlying 4H-SiC crystal and allows the defects to have a predictable orientation during epitaxial growth. Accurate offcut angle control is important for crystal quality, channel suppression, and defect engineering precision.

Crystal Quality

- **Minimizing defect density**—Precise offcut ensures high crystal quality, thus reducing defect density and enhancing device reliability.
- **Improving material uniformity**—Accurate offcut leads to uniform epitaxial growth and crystal morphology, resulting in improved material quality and device performance.

Channeling Suppression

- **Enhancing ion implantation precision**—Accurate offcut optimizes the ion implantation processes, reducing the risk of ion channeling and enhancing device performance.
- **Ensuring uniform dopant distribution**—Precise offcut ensures uniformity in the ion implantation process, minimizing channeling effects and improving device uniformity.

Defect Engineering Precision

- **Optimizing dopant activation**—Accurate offcut facilitates controlled defect engineering, thus optimizing dopant activation and improving device performance.
- **Enhancing device reliability**—Precise offcut enables the creation of tailored defect profiles, enhancing device reliability and longevity in 4H-SiC–based electronics.

While offcut is important for both silicon (Si) and SiC wafers, its accuracy is more critical for SiC wafers due to its higher sensitivity to crystal defects. The offcut angle in Si wafers affects crystal defects and dislocations, but the impact is generally less severe compared to SiC because of the wider bandgap in SiC and higher operating temperatures, where defects propagate and lead to a higher density of crystallographic and surface defects. Therefore, precise offcut in SiC is crucial for device performance and reliability, as it is essential for minimizing defects and ensuring high crystal quality.

Role of HRXRD in 4H-SiC Ion Implantation

HRXRD offers several advantages for accurately and precisely measuring wafer offcut angles in 4H-SiC substrates, including:

- **High accuracy**—HRXRD provides precise measurements of lattice orientation and offcut angles (magnitude and direction) with sub-degree resolution, ensuring the accurate detection of small deviations in the expected 4H-SiC wafer orientation.
- **Non-destructive analysis**—HRXRD allows for the characterization of wafer offcut without damaging the sample, enabling in-line metrology.
- **Versatility**—HRXRD can be applied to various SiC substrates with different orientations, sizes, doping levels and polytypes, making it versatile for various SiC device fabrication processes.

Bruker HRXRD for Rapid Offcut Determination

HRXRD is a power reference metrology technique used within silicon and compound semiconductor manufacturing. Bruker's advanced HRXRD systems enable an additional level of sensitivity to subtle changes in wafer offcut, with unparalleled accuracy and precision. This is achieved by measuring a series of high-resolution rocking curves (ω scans) at different azimuth (ϕ) angles to calculate the offcut magnitude and direction from the diffracted angles, as shown in Figure 2. This sequence of measurements is fully recipe-driven and the analysis can be automated in the Bruker analytical software.

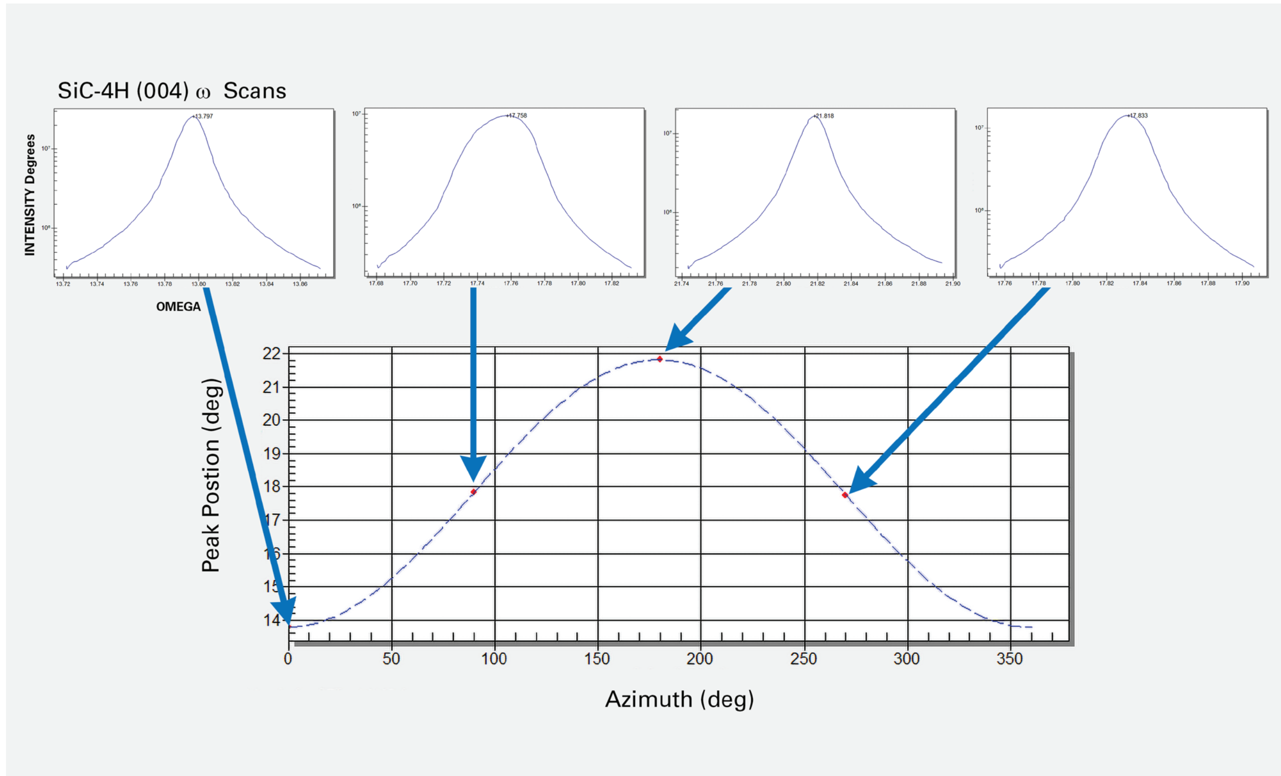

FIGURE 2.

Illustration of the offcut calculation by measuring ω rocking curves at different wafer azimuth within the recipe.

Furthermore, the precise offcut measurements could be further optimized and performed more rapidly if the nominal wafer thickness and expected offcut information are provided as a reference for offcut refinement. This is especially advantageous in high-volume manufacturing where the nominal wafer thicknesses and offcuts are well controlled. Recent tests performed on a dedicated high-intensity Bruker QCVelox HRXRD diffractometer showed a typical 200 mm 4H-SiC wafer with an expected 4° offcut can be measured in under 60 seconds with both accuracy and precision of <0.005° for offcut magnitude and <0.01° for offcut direction compared to the traditional method illustrated in Figure 2. This technique is suitable for the characterization of all common semiconductor substrates, including SiC, Si, GaAs, InP, GaN, and others.

Optimize Ion Implantation by Leveraging HRXRD

Ion implantation stands as a critical process in 4H-SiC semiconductor manufacturing, necessary for precise control over dopant distribution and device characteristics. By leveraging HRXRD for accurate wafer offcut, semiconductor manufacturers can optimize ion implantation processes and advance device performance in 4H-SiC–based electronics, driving innovation and enabling new applications in the electronics industry.

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