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Defect Electronics in SiC for High-Voltage Power Devices and Future Prospects

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Through recent progress in SiC bulk and epitaxial growth technology, 150-mm-diameter SiC (4H polytype) epitaxial wafers with a reduced density of extended defects are now commercially available. Combining with progress in SiC device technology, implementation of medium-voltage (~ 1 kV) SiC Schottky barrier diodes and power MOSFETs has enabled remarkable improvement of energy efficiency in various power electronic systems. However, extended and point defects present in the SiC epitaxial wafers still affect the performance and reliability of SiC power devices.

In this paper, recent progress in SiC defect electronics for high-voltage (both unipolar and bipolar) power devices and future prospects are reviewed. Regarding the material issues, fast epitaxial growth of high-purity epitaxial layers and reduction of basal plane dislocations have made significant strides. Growth technology of 100 μm-thick epitaxial layers intentionally doped to 1×10^{14} cm^{-3} with a basal plane dislocation density below 0.1 cm^{-2} has been established. The carrier lifetimes can remarkably be enhanced from about 2 μs (as-grown) to 50 μs or even longer by carbon-vacancy elimination (A 200 μm-thick carbon-vacancy-free (carbon vacancy density < 3×10^{10} cm^{-3}) region can be created). Trials of lifetime control by several techniques have been also successful. Current understanding of Shockley-type stacking faults in SiC, which cause "bipolar degradation", as well as carrier-recombination dynamics that determines the carrier lifetime in SiC based on physical models (electronic energy consideration for stacking faults and rate equations for carrier recombination, respectively) are presented. Using very thick (> 100 μm) and high-purity epitaxial layers, 15-29 kV SiC pin diodes and various switching devices such as insulated gate bipolar transistors have been demonstrated. The enhancement of carrier lifetimes is beneficial for remarkable improvement of on-state characteristics of SiC bipolar devices. Although the performance of these ultrahigh-voltage devices is promising, further improvement of the performance and reliability is required for system applications. Technological challenges in both the material and device fabrication are discussed.

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