Reverse breakdown tests of high voltage (1-kV rated) 4H-SiC junction diodes made from commercial epitaxial material

Igor V. Grekhov, Pavel A. Ivanov*, Pavel B. Rodin and Tat'yana P. Samsonova
Ioffe Institute of RAS, St. Petersburg, Russia, http://www.ioffe.ru

High voltage (1-kV rated) 4H-SiC $p^+n_on^+$-diodes were fabricated from commercial epitaxial material and tested with respect to low power (static) and high power (pulsed) reverse breakdown behavior. Two novel approaches to 4H-SiC epitaxial junction edge termination are proposed and realized. In both methods, high temperature (1700 - 1800°C) boron diffusion from a local implanted source is used to compensate n-type dopants at the edge of the pn-junction. Diodes of first type were made with shallow mesa-type junctions as floating guard rings. Diodes of second type were made using deep dry etching to form 10-μm (vertical wall) mesa-type structures.

In diodes fabricated, very sharp low power (static) avalanche breakdown was observed at a reverse voltage V_b of about 1000 V. The critical electric field was calculated to be 2.7×10^6 V/cm which is very close to the theoretical limit for the parallel plane 4H-SiC p^+n_o-junction with n_o-base doped at $(1.9 - 2)\times10^{16}$ cm^{-3}. The leakage current does not exceed 5×10^{-5} A/cm^2 at reverse voltages $V < 0.9V_b$. The diodes withstand avalanche current of 1 A/cm^2.

High power (pulse) reverse breakdown tests were performed on the fabricated diodes to detect possible excitation of fast impact ionization front (FIIF). Input voltage pulses were formed by a special generator build on Si drift step recovery diodes and Si avalanche sharpeners. The generator has adjustable pulse amplitude of 3 - 6 kV and pulse rise time of 1 ns or 0.2 ns. All tested 4H-SiC diodes did not stand the tests showing catastrophic failure at specific points within the main junction. Visualization of the diode electroluminescence under reverse and forward bias together with molten KOH etching revealed the presence of non-micropipe defects like threading dislocations and (0001) basal plane dislocations (BPDs). The total density of dislocations is estimated to be $(1 - 3)\times10^4$ cm^{-2}. The space-charge distortion effects were found to restrict the breakdown power density at the dislocation-related microplasmas.

Currently available commercial 4H-SiC wafers and epilayers contain many non-micropipe crystal defects. As a result, multi-amp high voltage avalanche devices like FIIF-diodes seem guaranteed to contain electrical nonuniformities that impact device operation. However, at ICSCRM-2005 (Pittsburgh PA, September 2005), Cree reported the progress in reducing the density of BPDs to 10 - 20 cm^{-2}. This raises a hope that uniform breakdown can be achieved in 4H-SiC diodes made from epitaxial material of such quality that allowing creation of high power picosecond avalanche sharpeners.