DESIGN, FABRICATION AND CHARACTERIZATION OF HIGH VOLTAGE 4H-SIC JUNCTION RECTIFIERS FOR POWER SWITCHING APPLICATIONS

by

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As material issues are addressed, proper device design promises to play a critical role in the commercialization of 4H-SiC bipolar diodes. This thesis investigates promising techniques to improve the switching characteristics of 4H-SiC bipolar diodes using numerical simulations and fabricated prototypes. Two approaches, emitter injection efficiency tailoring and novel structures, Epitaxial Refill Static Shielded Diodes (ER-SSD), are experimentally demonstrated for 10kV applications.

Baseline epitaxial and implanted anode PiN diodes are fabricated using 110μm thick, lightly doped drift layers. The low forward voltage drop, V_F=4.0-4.2V (J_F=100A/cm^2), of the epi-anode diodes shows significant conductivity modulation, further evidenced by diode switching characteristics. A reverse recovery charge density of $Q_{rr}\approx$11μC/cm^2 is observed when switched from J_F=100A/cm^2 at room temperature and increases to $Q_{rr}\approx$24μC/cm^2 at T=225ºC.

The new ER-SSD use shallow implanted P-channels and epi-P^+ regions to tailor the stored charge in the drift region under forward bias. Simulated tradeoffs illustrate superior switching performance, reducing Q_{rr} by up to 30% and the reverse peak current density, J_{RP} by 50% compared to a PiN. The improved switching performance is also evidenced by the first reported 4H-SiC ER-SSD showing over a 50% lower Q_{rr} and J_{RP} than co-fabricated PiN diodes, while exhibiting forward voltage drops of V_F=5-6V at J_F=100A/cm^2.

PiN diodes with reduced emitter injection efficiency are also used to improve switching performance. Diodes with thin (0.25μm) P^+ anodes achieve up to 40% lower Q_{rr} and J_{RP}, compared to the baseline PiN design. The emitter controlled diodes also exhibit the attractive characteristic of a positive temperature dependence of forward voltage drop at typical operating bias, with a room temperature V_F=4.5V increasing by less than 10% at T=200ºC.

High voltage blocking is achieved using a novel Multi-zone, Single Implant Junction Termination Extension (MZ-SI JTE). The new termination promises good performance sensitivity to process variations while decreasing fabrication cycle time. Simulation results show over 90% of the one-dimensional limit can be achieved with the target design and the desired 10kV blocking is maintained with up to +/-50% variation in JTE doping. Fabricated devices demonstrate the effectiveness of the MZ-SI JTE with diode breakdown reaching the 10kV design goal.