

Area: Wide band gap semiconductors

## Electrically Active Traps in Bipolar 10 kV 8 A Silicon Carbide (SiC) PiN Diodes

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4H-Silicon Carbide (4H-SiC) bipolar PiN diode rectifiers demonstrated ultra-high breakdown voltage ( $V_{BR} > 10$  kV), high current handling capability ( $> 8$  A), low reverse leakage current, and drift conductivity modulation, as compared to the well-developed 4H-SiC Schottky barrier diodes (SBDs). The concentration of the performance-limiting trap such as  $Z_{1/2}$  ( $E_C - 0.67$  eV) in the n-type 4H-SiC epilayer has been considerably reduced ( $< 5 \times 10^{12}$  cm<sup>-3</sup>) in recent years. The PiN diode structure integrates double p-type layers (p and p<sup>+</sup>). The p-type 4H-SiC layer quality is sub-standard than the n-type. The periphery protection was realized by Al<sup>+</sup> ion-implantation (p<sup>+</sup>). The ion-implantation-induced crystal defects introduce electrically active traps and affect the PiN diode characteristics via charge trapping. So, this work focuses on identifying the traps in the 4H-SiC PiN diodes by deep-level transient Fourier spectroscopy (DLTFS).

The 4H-SiC PiN diodes with a DC blocking voltage of 10 kV and a continuous forward current of 8 A were used for this study. The active area of the diodes is about 8.69 mm<sup>2</sup>. The junction termination extension (JTE) technique was employed in the diode structure to mitigate the electric field crowding at the junction edges (p<sup>+</sup> periphery production), thus yielding theoretically anticipated on-state and off-state performance.

The forward voltage drop across the diode at 1 mA is  $\sim 2.6$  V. It is found that negligible current flow occurs for low forward bias  $< 1.6$  V, then the diffusion current governs the forward current up to 2.7 V, beyond that series resistance effect comes into the picture. The diode exhibits a low reverse leakage current  $< 0.5$  nA at -200 V. It is noted that the forward voltage drop decreases with the temperature rise due to the increase in intrinsic carrier concentration, at the same time on-state current increases; thus on-state conduction losses reduce with temperature. The reverse I-V (0 V to -200 V) remains unchanged even at 150°C, signifying the effectiveness of 4H-SiC PiN diodes for the elevated temperature operation.

Figure 1 shows the capacitance-DLTFS spectra acquired at two different emission transients ( $T_E = 20.48$  ms and 2.048 s). In our measurements, positive and negative DLTFS peaks correspond to electron trap (located below conduction band  $E_C - E_T$ ) and hole trap (i.e.  $E_V + E_T$ ), respectively. Three hole traps H1 at  $E_V + 0.16$  eV, H2 at  $E_V + 0.3$  eV, and H3 at  $E_V + 0.63$  eV and two electron traps E1 at  $E_C - 0.19$  eV and E2 at  $E_C - 0.67$  eV are identified in PiN diodes using Arrhenius analysis. Among these, electron traps  $E_C - 0.19$  eV (Ti) and  $E_C - 0.67$  eV ( $Z_{1/2}$ ) are omnipresent defects in the n-type 4H-SiC layer. The hole traps namely  $E_V + 0.16$  eV,  $E_V + 0.3$  eV, and  $E_V + 0.63$  eV may be originated from the ion-implanted p<sup>+</sup> JTE region.

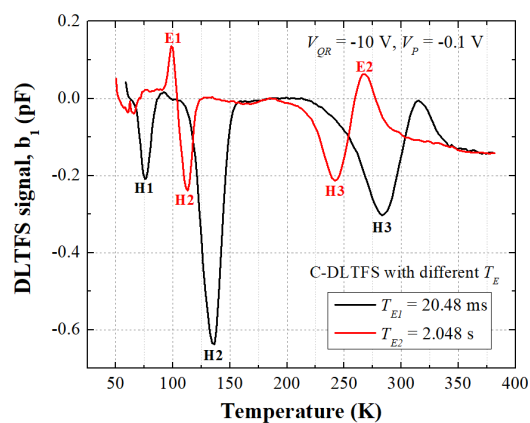


Figure 1: Capacitance-DLTFS spectra acquired at two different emission transients ( $T_E = 20.48$  ms, 2.048 s) reveal three hole traps H1, H2, H3, and two electron traps E1 and E2 in the 4H-SiC PiN diodes.