

Electrical Characteristics and Carrier Lifetime Measurements in High Voltage 4H-SiC PiN Diodes

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The availability of higher quality, thicker epi-layers has led to the demonstration of SiC PiN rectifiers with blocking voltages as high as 20kV [1, 2]. Perhaps more encouragingly, large area 10kV diodes with a low forward voltage drop of 3.75V (@ $J_F=100\text{A}/\text{cm}^2$, $I_F=50\text{A}$) have been presented, exhibiting sufficiently long carrier lifetimes to modulate the conductivity of lightly doped blocking layers under forward bias [3]. However, as discussed in [4-5], determining the carrier lifetime in SiC diodes is more difficult than in their silicon counterparts.

In this work, drift layer carrier lifetimes in 4H-SiC PiN diodes have been extracted using electrical transient characteristics, simulated device performance and microwave photoconductivity decay (M-PCD) measurements of commercial starting material [6]. High voltage PiN diodes were fabricated using 110 μm thick, lightly doped ($N_D=6\times 10^{14}\text{cm}^{-3}$) epi-layers. A two-step anode was subsequently grown in our horizontal, coldwall CVD reactor, including a 1.1 μm thick p-type ($N_A\sim \text{mid-}10^{18}\text{cm}^{-3}$) epi-layer and a 0.25 μm p⁺ cap layer ($N_A>1\times 10^{19}\text{cm}^{-3}$) to ensure good ohmic contact. Device isolation is achieved by RIE mesa etching and multi-zone, implanted JTE termination described in [7] is used to achieve high blocking voltage ($BV \approx 8\text{kV}$).

Fig. 1 shows the reverse recovery current waveforms of a typical diode at various temperatures. The characteristics indicate an increase in carrier lifetime at elevated temperature with the extracted Q_{rr} increasing from about 2.5 $\mu\text{C}/\text{cm}^2$ at room temperature to 6 $\mu\text{C}/\text{cm}^2$ at $T=225^\circ\text{C}$. Using numerical (MEDICI) simulations we show, in this paper, reverse recovery characteristics often yield inaccurate measurements of carrier lifetime in SiC PiN diodes and that Open Circuit Voltage Decay (OCVD) is a more robust method, useful even with the presence of low-lifetime regions in the anode or at the metallurgical junction. OCVD measurements are used to extract drift layer carrier lifetimes using the circuit shown in Fig. 2. Room temperature lifetimes ($\tau \approx 0.6\mu\text{s}-0.8\mu\text{s}$) are found to be comparable to previously reported M-PCD measurements taken on the commercial starting material [6]. As expected, the lifetime increased at elevated temperature (to $\tau \approx 2\mu\text{s}$ at $T=225^\circ\text{C}$), shown in Figs. 3-4.

The carrier lifetime and resulting conductivity modulation of the drift layer is further evidenced by good agreement between the simulated and experimental forward I-V performance illustrated in Fig. 5. By comparing experimental and simulated electrical characteristics, we will also present the effects of injection efficiency, anode lifetime and residual interface damage on the performance of high voltage 4H-SiC PiN diodes.

Acknowledgement:

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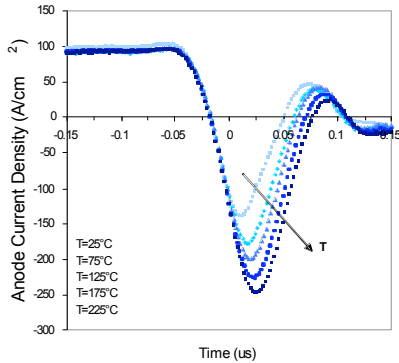


Fig. 1 Reverse recovery current of epi-anode PiN ($A=1.1 \times 10^{-3} \text{ cm}^2 V_R=60\text{V}$)

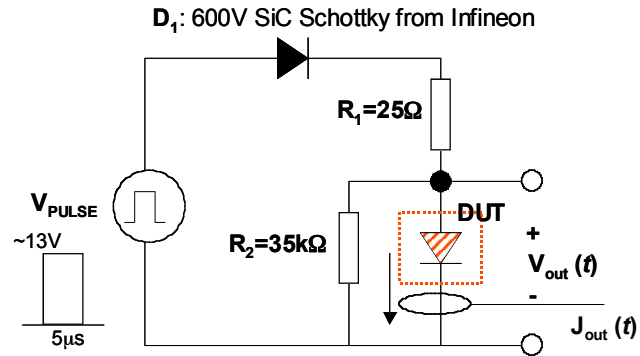


Fig. 2 Open circuit voltage decay (OCVD) test circuit used to extract carrier lifetime

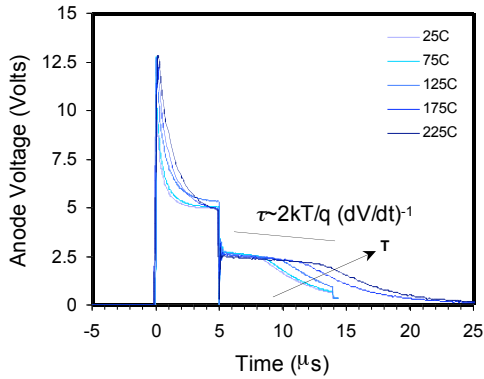


Fig. 3 OVCD measurements of epi-anode PiN diode at elevated temperature

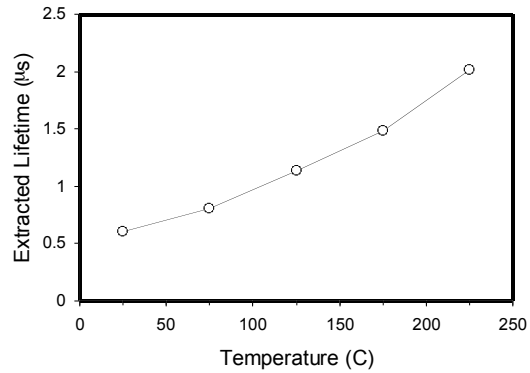


Fig. 4 Carrier lifetime extracted from OCVD measurements versus temperature

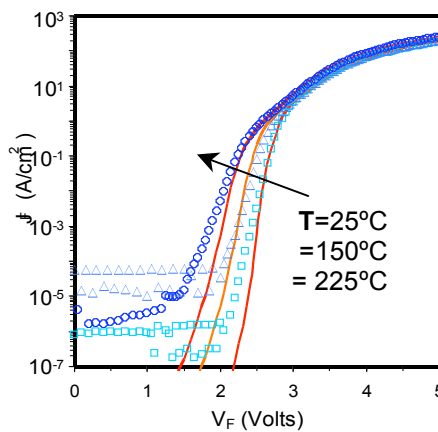
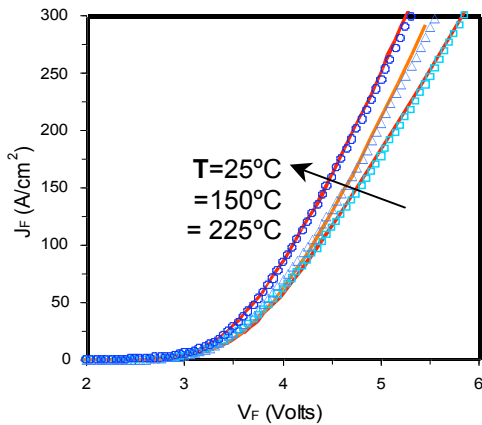


Fig. 5 Simulated (-) and experimental (O, E, □) forward I-V characteristics of 4H-SiC PiN diodes Simulations include carrier lifetime extracted from OCVD measurements (measured p-contact resistance $\rho_C \approx 10^{-3} \Omega\text{-cm}^2$ included in forward I-V simulations)