GaN-on-GaN PiN Diode Performance at Cryogenic Temperatures

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Spacecraft based electronic systems require cryogenic temperatures for their operation. Hence, it is of paramount importance to design power electronics systems that can operate efficiently under these conditions. A recent review [1] of power semiconductor devices at cryogenic temperatures included SiC Schottky diodes and GaN High Electron Mobility Transistors (HEMT), but no studies have been reported on the electrical behavior of GaN based diodes. This paper presents a comprehensive study of the performance of GaN-on-GaN PiN diodes at cryogenic temperatures.

A schematic cross-section of a fabricated GaN-on-GaN PiN diode is depicted in Fig. 1. The epitaxial structure comprises of 300 nm p GaN, 8 µm n^- GaN and 350 µm n^+ GaN. Multiple metal layers of Ti/Al/Ti/Au were deposited consecutively on the backside of substrate, and subsequently annealed at 825°C for 30 s in N_2 ambient to form an ohmic contact. Finally, Ni/Au metals were deposited on the p GaN and annealed at 550°C for 10 minutes in O_2 ambient to form the anode electrode. Current-voltage (I-V) measurements were recorded over the temperature range from 300 K down to a cryogenic temperature of 80 K. The forward voltage current density and on-resistance (R_{on}) curves are shown in Fig. 2. The turn-on voltage (V_{on}) is found to be 3.48±0.06 V (@ J=1 A/cm^2), while the forward voltage and on-resistance are 5.66±0.1 (@ J=100 A/cm^2), and 22.39±3.16 mΩcm^2, respectively. The temperature dependent forward I-V curves are shown in Figs. 3-4. It can be seen from the inset of Fig. 3 that V_{on} increases as temperature decreases. A similar trend can be seen for R_{on} from Fig. 5. The total on-resistance consists of the resistances of drift layer, substrate, and contact, each with a different contribution. The carrier concentration in the n^- GaN layer is extracted to be 4.55×10^{16} cm^{-3}, as shown in Fig. 6. The total current density has been estimated as the sum of separate contributions, according to the schematic in Fig. 7. The results indicate the dominance of Shockley-Read-Hall recombination [2] and its strong sensitivity to temperature. Due to the higher activation energy of Mg and Si in GaN, the physical model of incomplete ionization [3] is introduced in the modelling of the current to investigate the impurity freeze-out effect. Furthermore, the temperature dependent band gap [4] and mobility [5] models are included and will be discussed in detail in the full paper. Unlike GaN HEMTs [1], the carrier freeze-out has been observed in the GaN-on-GaN PiN diode. Further optimization and improvements of the diode model is required to explain current transport at cryogenic temperatures.

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References

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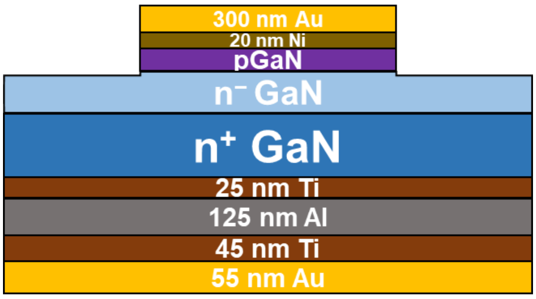

Fig. 1 Schematic cross-section of GaN-on-GaN PiN diode.

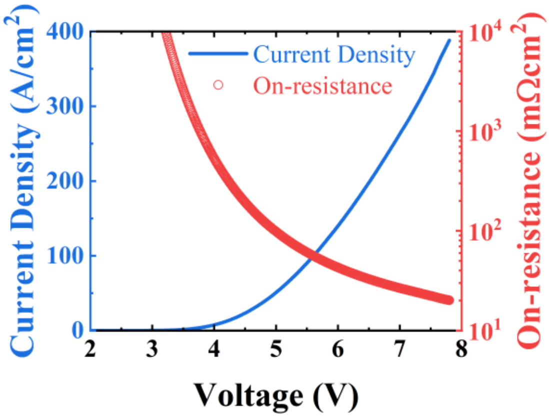

Fig. 2 Forward J-V and R_{on} vs. voltage curves.

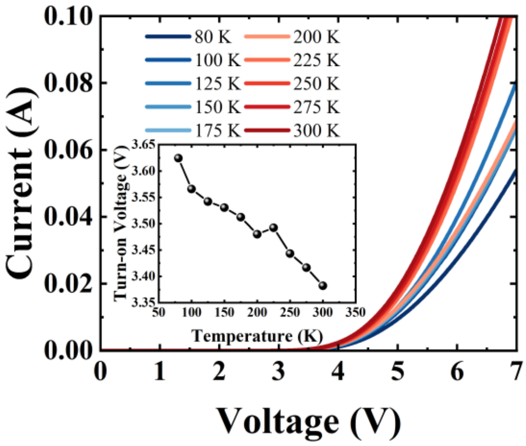

Fig. 3 Temperature dependent I-V curves on a linear scale with V_{on} vs. temperature in the inset.

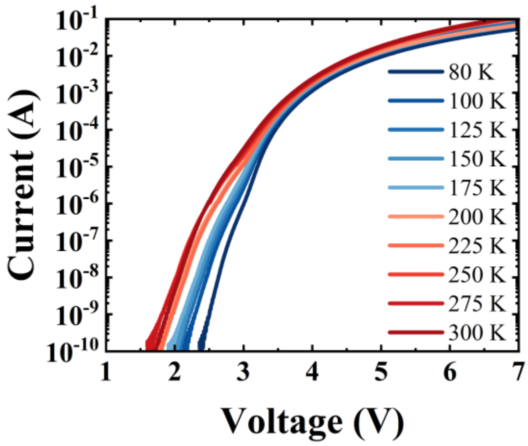

Fig. 4 Temperature-dependent I-V curves on log scale.

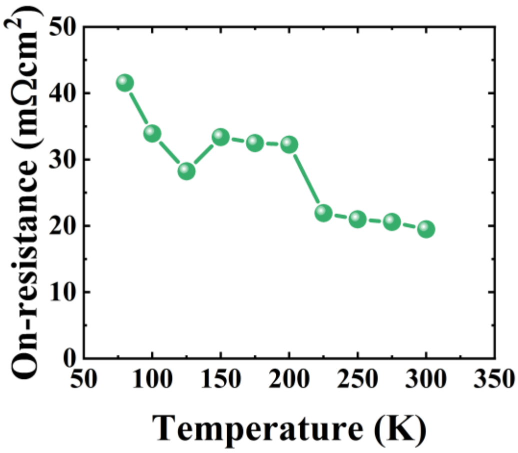

Fig. 5 On-resistance versus Temperature

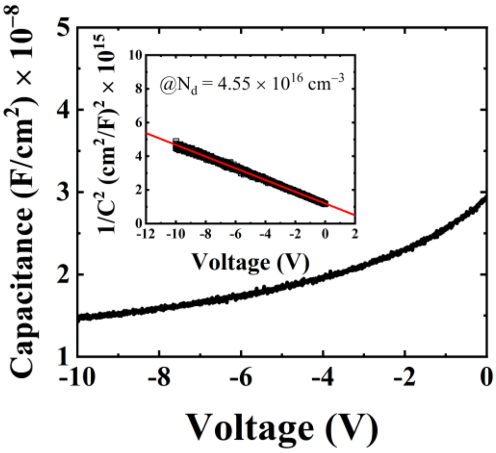

Fig. 6 C-V and $1/C^2$ vs. voltage in the inset.

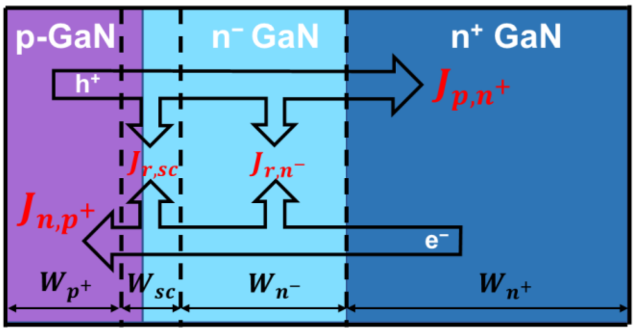

Fig. 7 The cross-section of p GaN - n^- GaN - n^+ GaN showing contribution of several current components (diffusion and recombination) considered in modelling experimental I-V curves at cryogenic temperatures.