Investigation of the Kink Effect in GaN HEMT Technology Using Fermi Kinetics Transport

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High frequency, high power electronic components are required for a variety of commercial and Air Force applications. For example, wireless communication networks require RF power amplifiers for cellular base stations [1], and power switches are an important part of the electrical utility grid [2]. Because of its wide bandgap, high breakdown voltage, and large peak electron velocity, gallium nitride (GaN) is an attractive material for discrete power amplifier transistor technology. Moreover, GaN's ability to form heterostructures and the spontaneous and piezoelectric polarizations of the heterostructures can be exploited to construct high electron mobility transistors (HEMTs) containing highly conductive two-dimensional electron gas channels with large electron densities and high electron mobility.

Despite great strides in GaN HEMT development, this device can also exhibit certain operational in-stabilities. One type of instability is called the kink effect or drain current knee walkout. It is characterized by a sudden increase in drain current at high drain voltage [3]. Instabilities like these are on-going issues that must be addressed for advanced power-switching applications.

The work reported here investigated the GaN HEMT kink effect by including electron trap dynamics in a computational physics framework developed by the Air Force Research Laboratory (AFRL). These tools simulate devices by solving Maxwell's vector field equations coupled to nonlinear electron transport including electronic band structure, quantum mechanical scattering, and hot electron effects. Figures 1 – 3 depict simulation details, and Figure 4 compares simulated electron drift velocities with Monte Carlo results obtained from the literature [4]. Figures 5 and 6 show that results calculated by the AFRL transport solver compare favorably with measurements from the literature.

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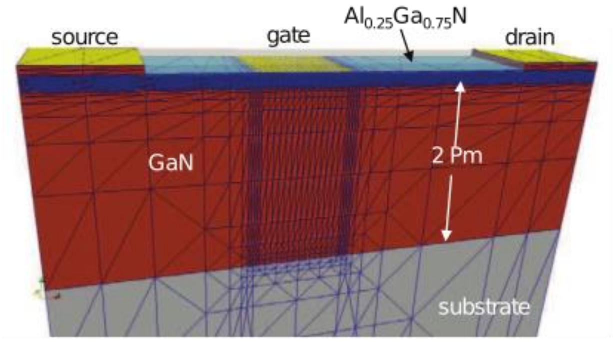

Fig.1: Simulated device structure similar to the GaN HEMT fabricated and characterized by Wang and Chen [5].

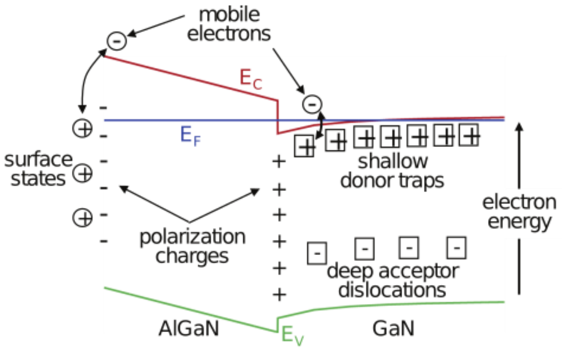

Fig.2: Polarization and defect charges typically located in a GaN HEMT.

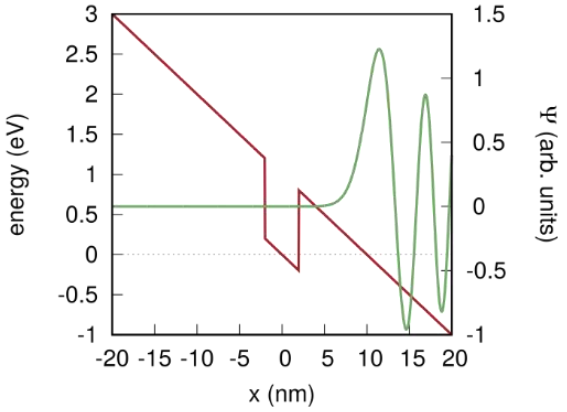

Fig.3: Airy function for an electron trap, approximated as a square potential well, in a constant electric field.

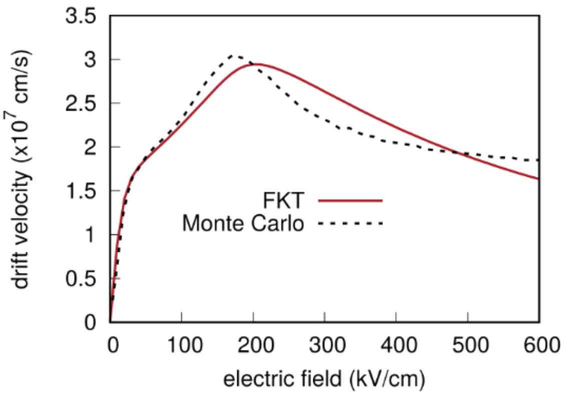

Fig.4: Electron drift velocity versus electric field computed with FKT using iso-energy integrals computed from GaN electronic band structure compared with Monte Carlo results [4].

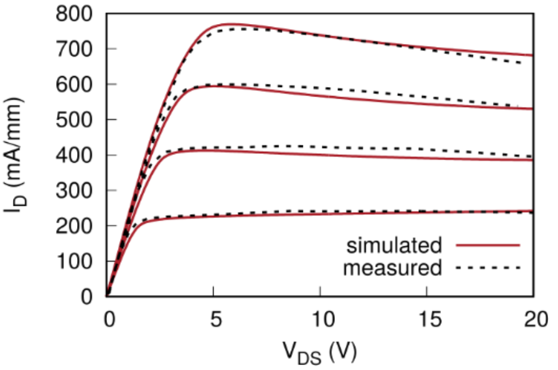

Fig.5: Drain current versus drain voltage for different gate biases. Measured data from Wang and Chen [5] under illuminated conditions and simulated with constant ionized trap density at GaN/AlGaN interface.

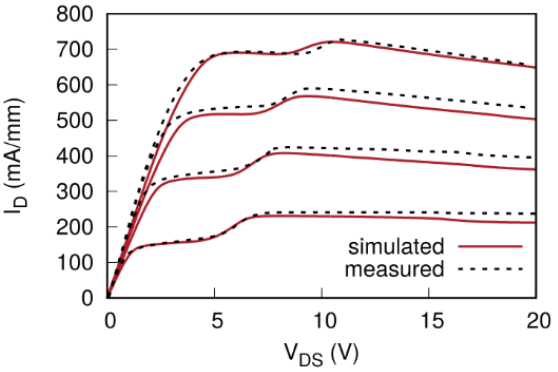

Fig.6: Drain current versus drain voltage for different gate biases. Measured data from Wang and Chen [5] without illumination and simulated with partially ionized GaN/AlGaN interface traps.