Reliability of GaN/AlGaN/AlN/GaN HEMTs: Current Degradation

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INTRODUCTION

AlGaN/GaN high-electron mobility transistors (HEMTs) are a very promising technology for switching and radio frequency applications due to high saturation velocity and large breakdown field of the GaN material [1]. However, the fundamental reliability problem associated with this technology, both in the off-state and the on-state has to be solved before its widespread use.

The two major reliability concerns with these device structures are: (1) the electric-field induced strain degradation also known as electromechanical coupling, and (2) the current collapse mechanism at high power operating conditions. The present work sheds light on the physics behind these two mechanisms that lead to reliability concerns in GaN HEMTs.

DISCUSSION

Polarization charge, being an inherent property of the GaN material system, is responsible for inducing the carriers in the channel region [1]. This charge comprises of two components, spontaneous and piezoelectric polarization charge. The stress between the layers in the HEMT structure is responsible for the piezoelectric polarization charge. The stress between the layers varies with the applied gate voltage and modulates this component of the polarization charge which, in turn, alters the channel carrier density [2].

In the present work, this model has been implemented into a particle based Monte Carlo device simulator for a GaN/AlGaN/AlN/GaN HEMT device (see Fig. 1). Current degradation of about 3 % for the worst possible case has also been observed.

The second major concern in the operation of these GaN HEMT devices is their thermal performance. The modeling of self-heating is very important in these devices as current collapse under high power operating conditions has been observed in several experimental studies. An electro-thermal based device simulator that consists of a Monte-Carlo Poisson equation solver self-consistently coupled with an energy balance solver for both acoustic and optical phonon bath has been developed at ASU. We observe that the lattice temperature increases to its steady state value (as shown in Fig. 2) taking several Gummel cycles and the electron temperature decreases to reach its steady state value. This suggests that the velocity of the particle is reduced with the increase in lattice temperature leading to the degradation in current.

The peak of the lattice temperature is under the gate to drain overlap region (see Fig. 3). This modulates the charge density in the channel and increases the vertical electric field in the growth direction (see Fig. 4) which can lead to trapping of the surface states leading to further degradation in output current as shown in Fig. 5.

The dependence of the peak lattice temperature and its profile on the time for energy transfer between the electron-acoustic-optical phonon systems is being evaluated at the moment and will be presented at the conference.

REFERENCES

[1] O. Ambacher et al., "Two-dimensional electron gases induced by spontaneous and piezoelectric polarization charges in N-and Ga-face AlGaN/GaN heterostructures", Journal of Applied Physics, vol. 85, pp. 3222-3233.
[2] B. Padmanabhan, D. Vasileska, S. M. Goodnick, "Electromechanical coupling in AlGaN/AlN/GaN HEMTs", in Proceedings of the Nanotech, pp. 679-681, 2011.

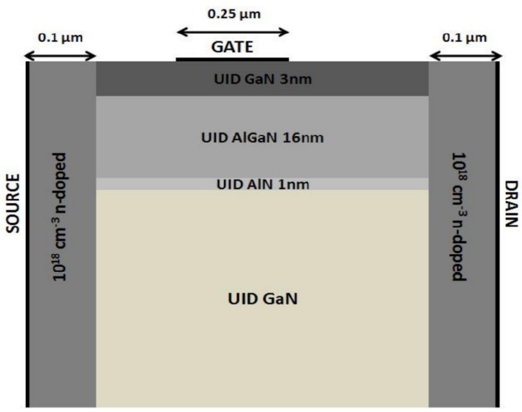

Figure 1. Device structure being simulated.

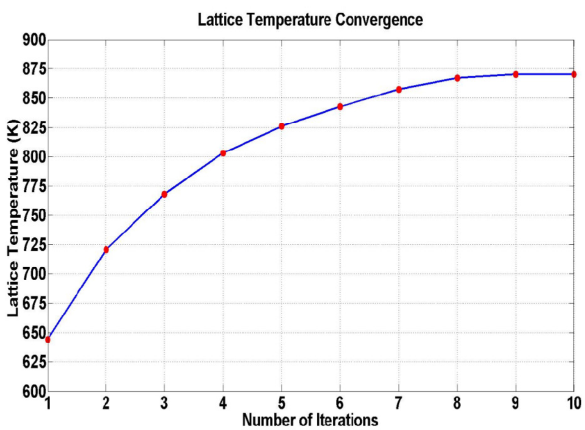

Figure 2. Lattice temperature convergence. Iteration corresponds to a complete Gummel cycle.

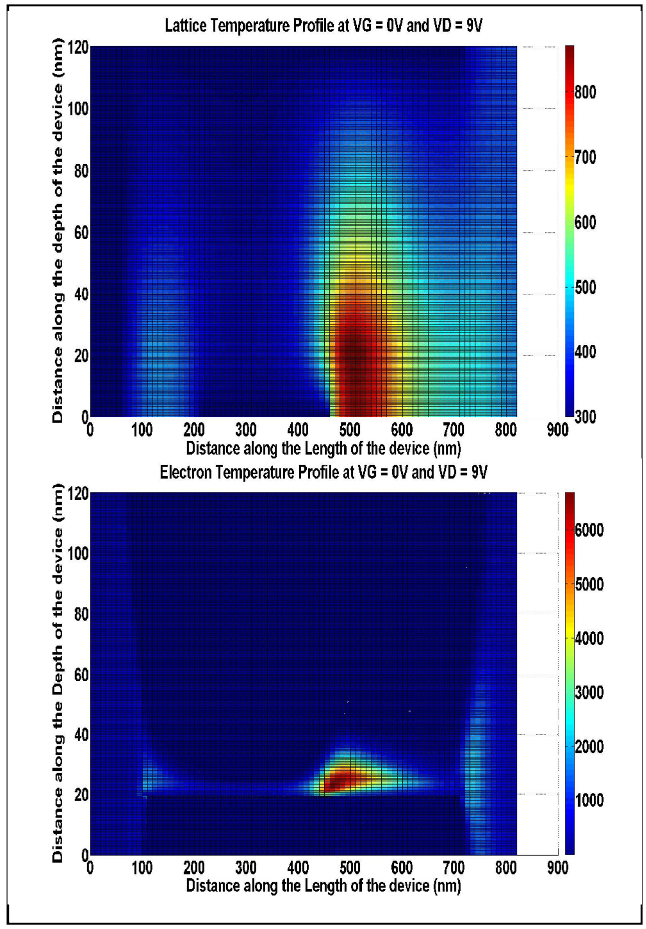

Figure 3. Lattice and Electron temperature profiles.

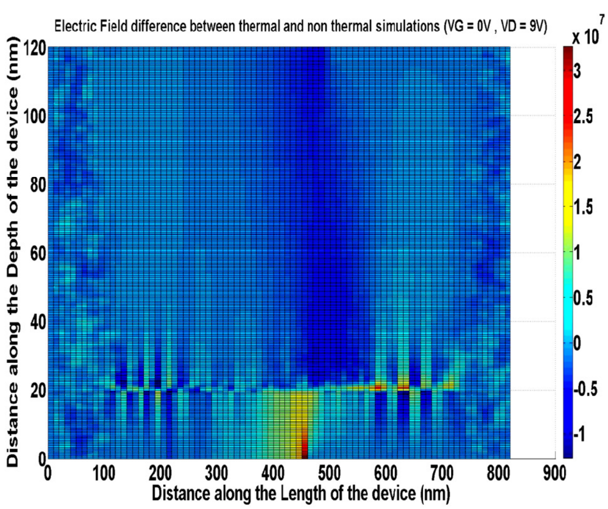

Figure 4. Electric field increase due to self-heating effects.

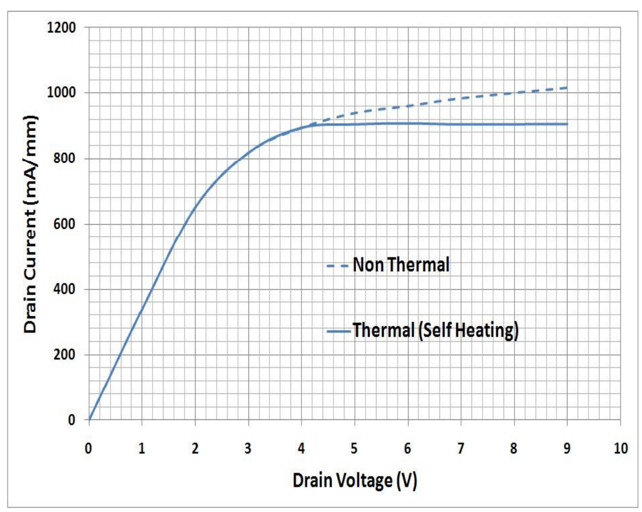

Figure 5. Output Characteristics for Vgs = 0V (Thermal Simulations).