Influence of Shielding on the Thermal Characteristics of GaN HEMTs

Balaji Padmanabhan, Dragica Vasileska and S. M. Goodnick
Department of Electrical Engineering
Arizona State University
Tempe, AZ USA
balajipad@gmail.com, vasileska@asu.edu, goodnick@asu.edu

Abstract— **One of the major concerns in the operation of GaN HEMT devices is its thermal performance. Under high power operating conditions, current collapse has been observed in several experimental studies. In the present work, the effect of shielding the GaN HEMT structure on the thermal characteristics and the gate-edge electric field of the structure is being investigated. An electro-thermal device simulator that couples the Monte Carlo transport kernel, the Poisson kernel and a thermal solver has been developed at Arizona State University to model the physics behind the operation of this device**

Keywords- GaN HEMTs, current collapse, self-heating, shielding, field-plate

I. INTRODUCTION

III-V materials have emerged as a very strong candidate for high power, high frequency and high temperature applications in the recent years [1-3]. Large band gap, high saturation velocity and the ability to support heterostructure has made them favorable for microwave applications. In heterostructure technology, two dimensional electron gas densities of the order of $10^{13}cm^{-2}$ or higher are achieved in AlGaN/GaN HEMT devices without intentional doping. This is due to the large piezoelectric polarization charge of the top strained layers and the inherent property of large spontaneous polarization charge of this material system [4].

Given the various advantages, their electrical reliability in both the on and the off-state operation regimes is still a fundamental problem to be solved before the widespread use of this technology can be made. The thermal performance of GaN HEMT is one of the major reliability concerns. Thus, the modeling of self heating is a very important aspect of understanding the operation of these devices. One of the main reasons for the collapse of drain current is attributed to the defects in the GaN layer and the interface between the passivation film and the AlGaN layer. The electron trapping in these defects is majorly influenced by the electric field at the gate edge, as shown in previous research studies [5] [6].

In the present work, an electro-thermal simulator has been utilized to study the thermal characteristics of the device and to evaluate shielding as being one of the ways to improve the thermal performance of GaN HEMT.

This work was supported by NSF grant under the contract No. ECCS-0901251. This work was also supported by a grant from the Army Research Laboratory. Program coordinator is Tsvetanka Zheleva.

The paper is organized as follows. In Section II, the key details regarding the simulator operation are briefly described. Device structure details and simulation results are presented in Section III. These results illustrate the influence of shielding on the thermal characteristics of GaN HEMT. Conclusions are presented in Section IV.

II. SIMULATOR

The electro-thermal device simulator shown in Figure 1, self-consistently couples the Poisson kernel, the Monte Carlo transport kernel and the thermal simulator. The thermal simulator consists of an energy balance solver for both the acoustic and optical phonon for accurate modeling of the nature of heat transfer in the device.

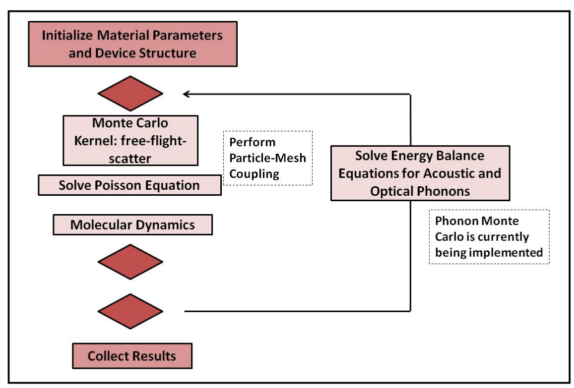


Figure 1. Flow chart of Electro-thermal simulator

It is well known that, in the presence of an electric field, the energy gained by the electrons is efficiently transferred to the optical phonons and a small portion of the energy is transferred to the acoustic phonons. The optical phonons have negligible group velocity. Therefore, they are not effective in the heat transport and a hot spot forms. After a while, through anharmonic processes optical phonons decay into acoustic phonons and the heat from the hot-spot gets transferred to the heat sinks. This process of energy transfer is clearly illustrated in Figure 2.

ISBN 978-0-615-71756-2

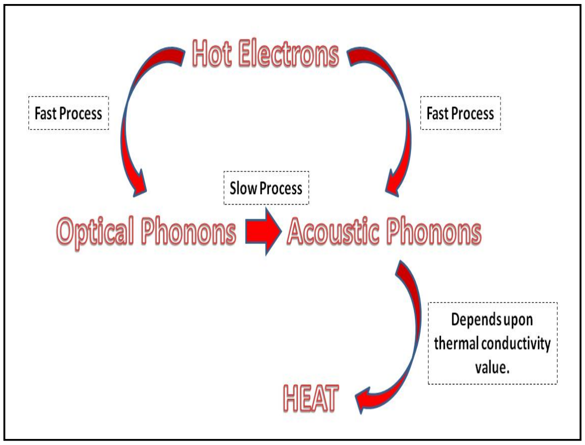


Figure 2. Flow chart of Electro-thermal simulator

As shown in Figure 1, the Monte Carlo is inside the energy-balance loop (Gummel cycle). It takes several Gummel cycles for the lattice and electron temperature to reach steady state values.

III. RESULTS

The device structure simulated in the present work is shown in Figure 3. The shield (field plate) lengths and the shield (field plate) dielectric thickness are varied to evaluate its influence on the thermal characteristics of the HEMT structure. The shield length, 'Lsh' has been varied from 0.05µm to 0.4µm and the shield oxide thickness, 'Tsh' has been varied from 20nm to 60nm.

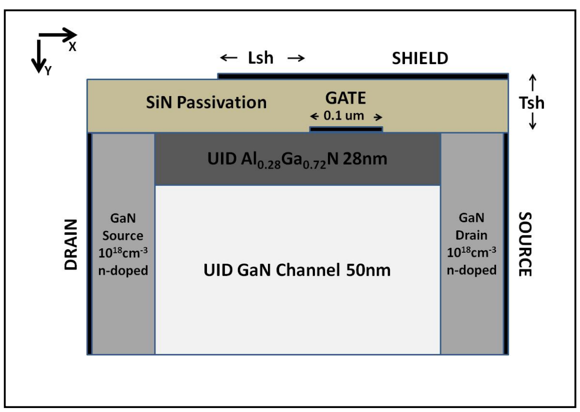
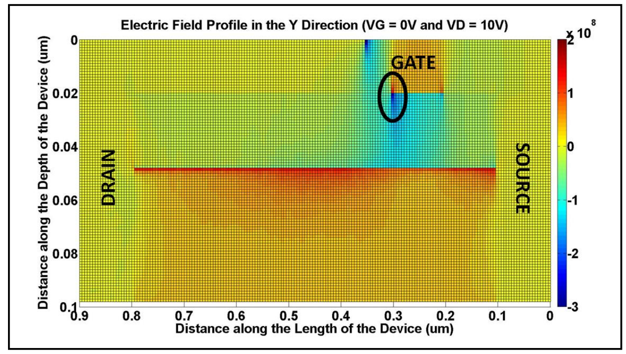


Figure 3. Flow chart of Electro-thermal simulator

We observe from the electric field profiles shown in Figure 4 that as the shield length increases, the electric field near the critical gate-drain edge reduces. This is because, as the shield electrode length increases, it spreads the electric field over a wider region. As the field near the gate-drain edge reduces, the potential for electron trapping in the defect sites also reduces and improves the reliability performance of the device.

(a)



(b)

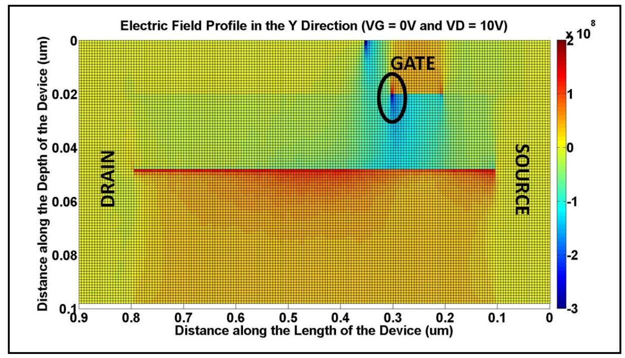


Figure 4. Electric field profile in the device with 0.05µm (a) and 0.4µm (b) shield lengths, respectively

The electric field varying with the shield length is shown in Figure 5.

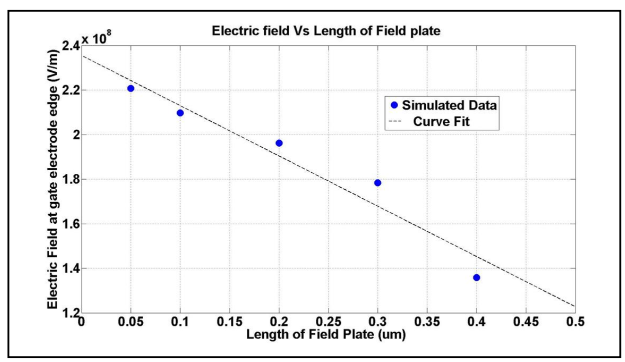


Figure 5. Vertical component of the Electric field at the gate-drain edge Vs the field plate length

As the peak electric field moves far away from the gate-drain edge, the peak electron velocity also moves with it. The peak lattice temperature follows the peak electron velocity, as the energy of the electrons is highest in this region. This is clearly illustrated in Figure 6.

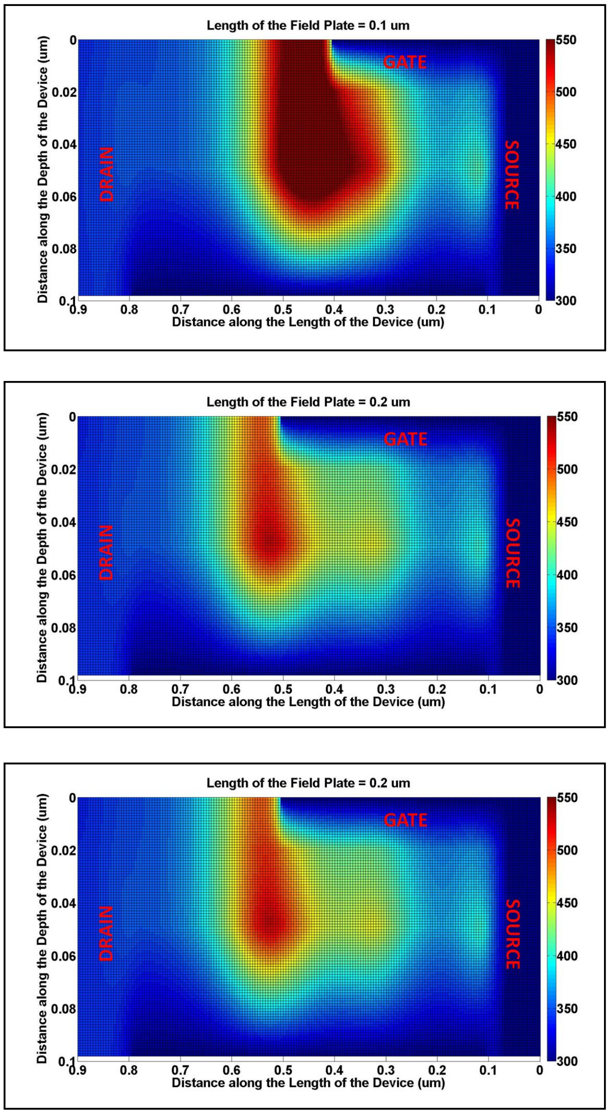


Figure 6. Lattice Temperature profiles in AlGaN/GaN HEMT for varying shield lengths

The shield dielectric thickness is also varied for two different shield lengths. Its influence on the gate-edge electric field is similar to the effect of shield length. As the shield dielectric thickness increases, its ability to capacitively couple the electric field with the structure reduces. This results in increase in the electric field near the gate drain edge for a given field plate length. The effect of the shield dielectric thickness on the electric field profiles for two different shield lengths are shown in Figure 7 and Figure 8.

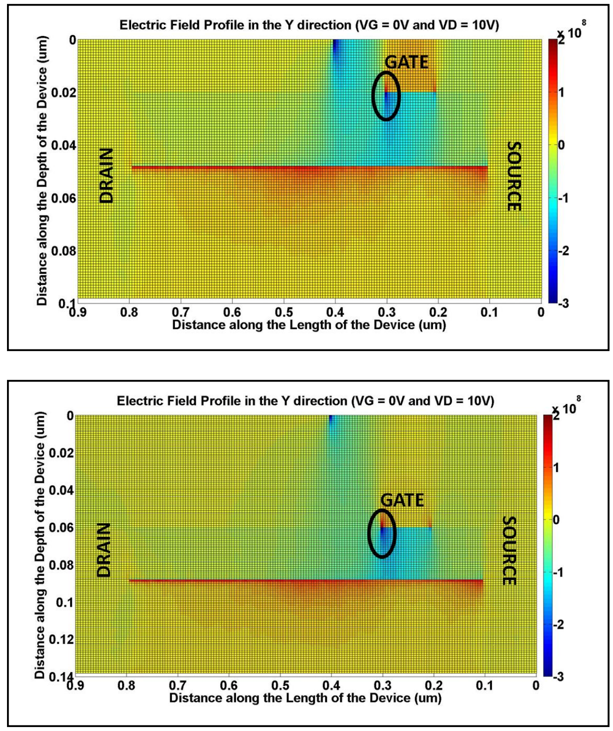


Figure 7. Electric field profile in the device for a shield length of 0.1µm (top) 20nm (bottom) 60nm shield dielectric thickness

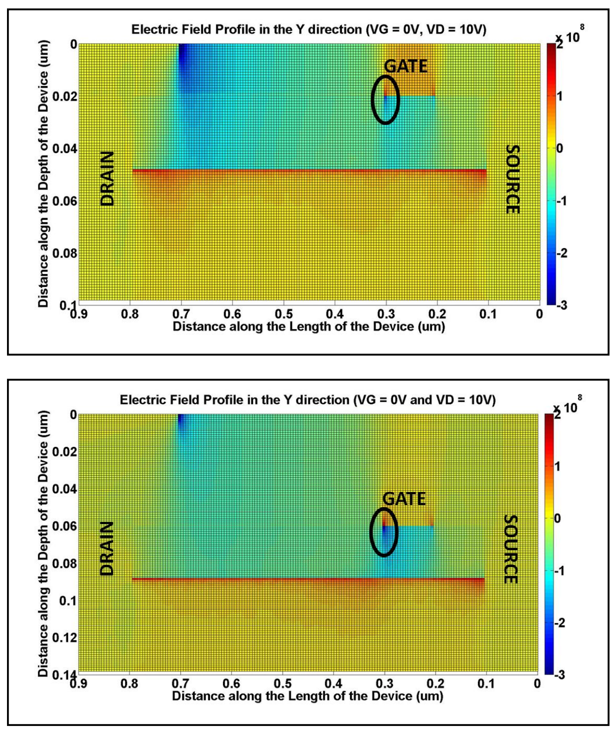


Figure 8. Electric field profile in the device for a shield length of 0.4µm (top) 20nm (bottom) 60nm shield dielectric thickness

The electric field at the gate drain edge for varying shield dielectric thickness and shield lengths is shown in Figure 9.

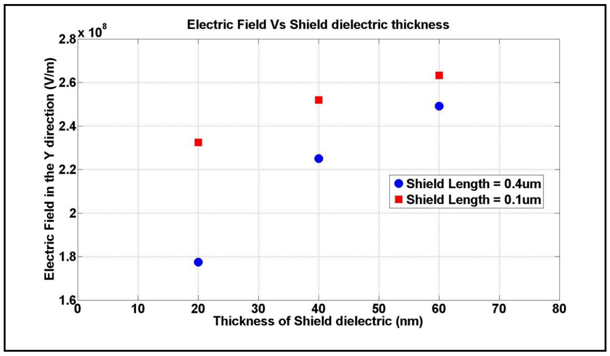


Figure 9. Vertical component of the Electric field at the gate-drain edge Vs the shield dielectric thickness for varying field plate length.

IV. CONCLUSIONS

An electro thermal particle based device simulator has been developed to understand the physics behind the reliability concerns in GaN HEMT technology. The effect of shielding on the electrical and thermal characteristics of the device has been evaluated in this work. We show that by shielding the device, the electric field near the critical gate drain edge is reduced. This helps in preventing the electrons from the channel to accelerate towards the surface and occupy the surface states that leads to degradation of the output current. We also observe that the peak lattice temperature moves away from the gate drain edge reducing the reliability concerns with respect to the thermal characteristics of the device.

REFERENCES

[1] T. P. Chow, and R. Tyagi, “Wide Bandgap compund semiconductors for superior high-voltage power devices,” ISPSD, pp. 84-88, May 1993.

[2] I. P. Smorchkova, L. Chen and T. Mates, L. Shen and S. Heikman, B. Moran, S. Keller, S. P. DenBaars and J. S. Speck, U. K. Mishra, “AlN/GaN and (Al,Ga)N/AlN/GaN two dimensional electron gas structures grown by plasma assisted molecular beam epitaxy,” J. Appl. Phys., vol. 90, pp. 5196-5201, Nov. 2001.

[3] Y. F. Wu, D. Kapolneck, J. P. Ibbetson, P. Parikh, B. P. Keller and U. K. Mishra, “Very-High Power Density AlGaN/GaN HEMTs”, IEEE Trans. Electron Devices, vol. 48, pp. 586-594, Mar. 2001.

[4] O. Ambacher, J. Smart, J. R. Shealy, N. G. Weimann, K. Chu, M. Murphy, W. J. Schaff and l. F. Eastman, R. Dimitrov, L. Wittmer and M. Stutzman, W. Rieger and J. Hilsenbeck,”Two-dimensional electron gases induced by spontaneous and piezoelectric polarization charges in N- and Ga- face ALGaN/GaN heterostructures”, J. Appl. Phys., vol. 85, pp. 3222-3233, Mar. 1999.

[5] W. Saito, I. Omura, K. Tsuda, ”High-Voltage GaN-HEMTs for Power Electronics Applications and Current Collapse Phenomena under High Applied Voltage,” CS Mantech Conference, 2007.

[6] B. Padmanabhan, D. Vasileska, S. M. Goodnick,”Is self-heating responsible for the current collapse in GaN HEMTs?”, J. Comp. Electronics, pp. 129-136, 2012.