# Cryogenic Investigation of Current Collapse in AlGaN/GaN HFETS

S. Nuttinck[1], S. Pinel[1], E. Gebara[2], J. Laskar[1], and M. Harris[3]

[1] Georgia Institute of Technology, School of Electrical Engineering, 791 Atlantic Drive Atlanta, GA, 30332 USA
E-mail: sn46@prism.gatech.edu, Phone: 404 894 9924, Fax: 404 894-5028

[2] Quellan Inc., 250 14th Street, Atlanta, GA

[3] GeorgiaTech Research Institute, Electro-Optics, Environment, and Materials Lab., Atlanta, GA

***Abstract*** **- Current collapse in AlGaN/GaN HFETs is investigated at low temperatures using a transient current monitoring technique. The carrier trapping and de-trapping mechanisms are studied, and two distinct relaxation mechanisms are observed. They are associated to the presence of two close deep energy levels in the bandgap.**

## I. Introduction

GaN-based transistors are of great interest because they offer high power handling capabilities, and high frequency operations. Power densities above 10W/mm, and cutoff frequency ($f_T$) above 70GHz have been reported [1]. However, the reproducibility of these devices is limited by instabilities related to material quality and trapping effects.

Current collapse (CC) is a trap related phenomenon. A signature of CC is a kink in the output characteristics of the device [2]. There have been several studies of CC in GaN-based transistors: Klein *et al.* have observed deep traps levels at 1.8eV and 2.85eV in GaN MESFETs using a spectroscopic technique [3], the presence of a 98meV capture barrier in GaN MESFETs was shown by Meneghesso *et al.* using phototransient experiments [4], CC during microwave power measurement on AlGaN/GaN HFETs has been observed and interpreted as a negatively biased virtual gate by Vetury *et al.* [5], and studies of the effect of SiN passivation on CC have been reported to sometime reduce CC effect in AlGaN/GaN HFETs [6].

We propose in this section to investigate current collapse in AlGaN/GaN HFETs at low temperatures using a transient current monitoring technique. The carriers trapping and de-trapping mechanisms are studied. Two distinct relaxation mechanisms are observed, and are interpreted as the presence of two close deep energy levels in the bandgap.

## II. Phenomenon Identification

The devices studied in this section are 2-finger AlGaN/GaN HFETs grown on a SiC substrate, with a total gate width ($W_G$) of 250µm and a gate length ($L_G$) of 0.35µm. The devices exhibit a cutoff frequency ($f_T$) around 30GHz, and a breakdown voltage around 70V.

Fig.1 shows the device drain-to-source current characteristics under static and pulsed mode operation. The DC-IV measurements are performed after biasing the device at $V_{DS}^{STRESS}$ and $V_{GS}$ greater than the threshold voltage ($V_{TH}$). A kink in the $I_{DS}(V_{DS})$ curves appears for $V_{DS}^{STRESS}$ greater than 10V (Fig.1, $2V<V_{DS}<8V$). This effect does not appear under pulsed measurements, and is a typical behavior of current collapse (CC) [2]. The current collapse effect is usually associated to surface states [3] or buffer trapping [2,5]. In the present situation CC occurs when a high drain-to-source voltage is applied, suggesting that in these devices CC is associated to buffer trapping: under high $V_{DS}$, hot channel carriers are injected into regions adjacent to the active channel, where they are trapped at deep defect sites [2,3].

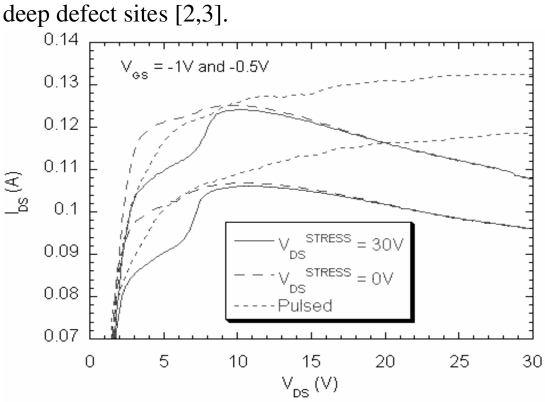


Fig.1. $I_{DS}(V_{DS})$ at 296K for various measurement conditions.

## II. Hot Carrier Injection

We define the parameter "depth of the collapsed region" as the difference of $I_{DS}$ in the collapsed region, between the characteristics obtained without trapping ($V_{DS}^{STRESS}$ =0V) and with trapping ($V_{DS}^{STRESS}$ >0V). This parameter is used to monitor the amount of trapped carriers.

Two parameters are reported to have an influence on the depth of the collapsed region: the drain-to-source voltage applied to the device that injects the electrons into the traps ($V_{DS}^{STRESS}$), and the duration of that stimulus.

Fig.2 shows the evolution of the depth of the collapsed region, measured at $V_{DS}$ = 7V, with a $V_{DS}^{STRESS}$ injection voltage applied during 20 seconds. When increasing $V_{DS}^{STRESS}$ from 12V to 20V the depth of the collapsed region increases from 1mA to 10mA, traducing an increase of the number of trapped carriers. $V_{DS}^{STRESS}$ determines the maximum number of defect sites that can be accessed by the carriers, and therefore the maximum depth of the current kink.

Fig.3 presents the influence of the voltage stimulus duration on depth of the collapsed region, and a saturation plateau is observed. The duration from which the plateau is observed corresponds to the time necessary for the carriers to populate all accessible defect sites.

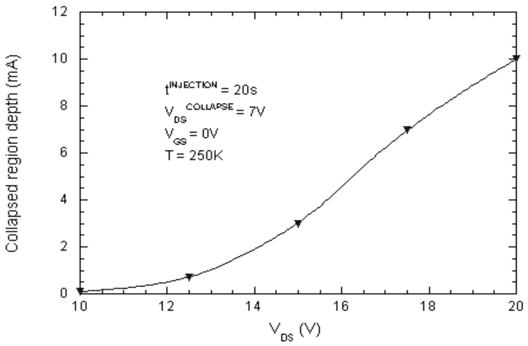


Fig.2. Evolution of the collapsed region depth after a $V_{DS}$ stimulus applied during 20 seconds, at T = 250K.

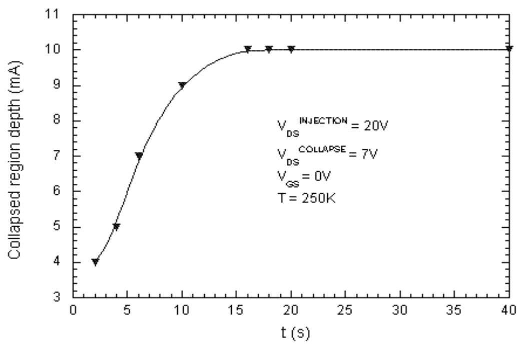


Fig.3. Evolution of the collapsed region depth after a $V_{DS}$=20V stimulus applied during t seconds, at T = 250K.

## III. Relaxation Mechanisms

The trapped charges can be released through illumination or thermal emission. Fig.4 illustrates the relaxation of the trapped electrons at 296K. Each of the $I_{DS}$ curves is measured after applying a 20V drain-to-source voltage for 5 second followed by a $V_{DS}$ sweep at fixed gate-to-source bias with an incremental delay.

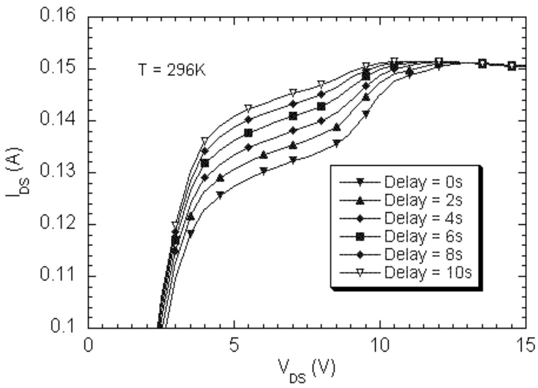


Fig.4. Relaxation of the collapsed region at 296K.

We propose in the next sub-sections to investigate the relaxation mechanisms by monitoring $I_{DS}$ in the collapsed region at various injection levels, and temperatures.

### A. *Impact of the Injection Level*

Fig.5 illustrates the relaxation of the collapsed region at 150K for various injection levels (controlled by the carrier-injection-duration). As already seen in Fig.3, increasing the carrier-injection time, gives more time to the carriers to get trapped, and therefore increases the depth of the current kink (visible at t=0s in Fig.5). It is noteworthy in Fig.5 that two relaxation mechanisms are observed at high injection level ($t^{INJECTION}$=20s in Fig.5). This is interpreted as the presence of two energy levels that participate to CC:

- At low injection level ($t^{INJECTION}$=4s in Fig.5) the injected electrons populate the lower energy level and only one relaxation mechanism is observed.
- While increasing the injection level ($t^{INJECTION}$=20s in Fig.5), the injected electrons saturate the accessible sites associated to the lower energy level and start populating the sites of higher energy. This results in a carrier emission that is a combination of the relaxation mechanism associated to both levels.

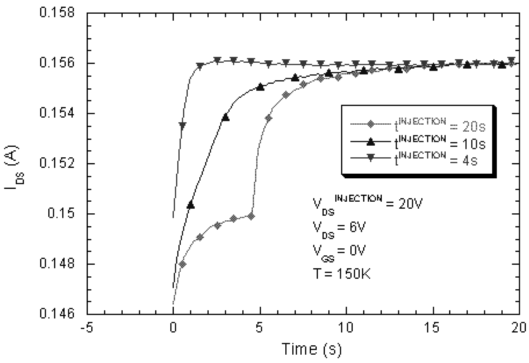


Fig.5. Drain-to-source current relaxation in the collapsed region for various injection levels, at 150K.

### B. *Impact of the Temperature of Operation*

Fig.6 illustrates the relaxation mechanisms at high injection level for various temperatures. It is noteworthy that when increasing the temperature from 150K the boundary between the two relaxation mechanisms becomes unclear. This is interpreted as the presence of the energy level of higher energy about (few x 10)meV above the deepest energy level: increasing the thermal energy broadens the energy levels ($k.T_{300K}$=25.9meV), and when the broadening is large enough to merge the two levels only one relaxation mechanism is observed. The time constants observed for the relaxation mechanisms suggest the levels are deep into the bandgap as reported in [3].

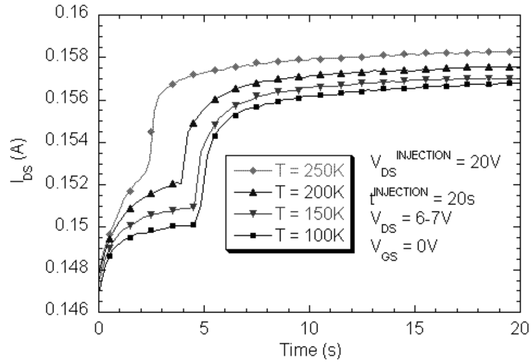


Fig.6. Drain-to-source current relaxation in the collapsed region at various temperatures, for a saturated injection level.

## IV. CONCLUSION

Current collapse in AlGaN/GaN HFETs has been investigated at low temperatures using a transient current monitoring technique. The carriers trapping and de-trapping mechanisms are investigated with respect to the injection level and to the temperature of operation. Two distinct relaxation mechanisms are observed at low temperatures and high hot carrier injection level. They are associated to two close deep energy levels in the bandgap. To our knowledge this is the first time that CC is investigated at low temperatures.

## ACKNOWLEDGEMENT


The authors wish to acknowledge J. Mulligan and W. Pribble from CREE N.C, for their support.


## REFERENCES


[1] L. Eastman, “Experimental Power-Frequency Limits of AlGaN/GaN HEMT’s”, IEEE MTT-S Digest, 2002, pp. 2273-2275.

[2] S. Binari, K. Ikossi, J. Roussos, W. Kruppa, D. Park, H. Dietrich, D. Koleske, A. Wickenden, and R. Henry, “Trapping Effects and Microwave Power Performance in AlGaN/GaN HEMTs”, IEEE Trans. on E.D., Vol. 48, No. 3, March 2001.

[3] P. Klein, S. Binari, K. Ikossi-Anastasiou, A. Wickenden, D. Koleske, R. Henry, and D. Katzer, “Investigation of Traps Producing Current Collapse in AlGaN/GaN High Electron Mobility Transistors”, Electronic Letters, Vol. 37, No. 10, pp. 661-662, May 2001.

[4] G. Meneghesso, A. Chini, E. Zanoni, M. Manfredi, M. Pavesi, B. Boudart, and C. Gaquiere, “Diagnosis of Trapping Phenomena in GaN MESFETs”, IEEE IEDM Symposium, pp.389-392, 2000.

[5] R. Vetury, N. Zhang, S. Keller, and U. Mishra, “The Impact of Surface States on the DC and RF Characteristics of AlGaN/GaN HFETs”, IEEE Trans. on E.D., Vol. 48, No. 3, March 2001.

[6] T. Kikkawa, M. Nagahara, N. Okamoto, Y. Tateno, Y. Yamaguchi, N. Hara, K. Joshin, and P. Asbeck, “Surface-Charge Controlled AlGaN/GaN-Power HFET Without Current Collapse and Gm Dispersion”, IEEE IEDM, Proceeding, pp. 585-588, 2001.