Threading Dislocations in GaN HEMTs on Silicon: Origin of Large Time Constant Transients?

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The significant decrease in microwave power output of GaN/AlGaN(or InAlN) HEMTs from the predicted DC load line curves is distinguished by current dispersion/slump [1]; a phenomenon exemplifying increase in knee voltage and decrease in the maximum channel current at pulsed biases. Electrically active traps held responsible for such collapse can be distributed anywhere in the band gap, and their characteristic time constants give rise to corresponding slow/fast transient. In past, dislocations have been attributed as a probable origin of slow transients though there is little qualitative data [2]. In this report, we present further consolidating evidence by scrutinizing the transient and pulse characteristics of two GaN/AlGaN channel based HFETs having significantly different dislocation density. The outcome should cause epitaxial engineers to strategize their growth accordingly on inexpensive substrates such as Silicon which generally creates high dislocation density in active epi-layers. This should ensure bulk commercialization of GaN-HEMT-on-Si technology in the form of RF power amplifier and switches, replacing the present leader III-As based HBTs and p-HEMTs which fall quite short in terms of the power performance offered by III-Nitrides.

Identical AlGaN/GaN HEMT layers have been grown on two different substrates namely Sapphire and Silicon (**Fig. 1**) by PAMBE equipped with N_2 RF source. It has been confirmed by plan view cross sectional TEM imaging that the GaN buffer and the following layers on Silicon possesses dislocation density of two orders higher than on Sapphire (**Fig. 2**). 2 μm long unpassivated HEMTs were processed on both wafers with optical lithography on the same run. These are probed with simultaneous gate and drain pulses with four different duty cycles (50%, 10%, 5%, and 1%) from four different bias points (Fig. 3 & 4.) To extract signature long emission constants of the traps (corresponding to deep levels) we have adapted the technique developed by [3] which is compatible with stress degradation and reliability tests. Accordingly, current transients for the devices were examined with without and with the application of off and on state pulses (**Fig. 5 & 6**) which helped us to explore different regions in the devices. Finally, the emission and capture time constants were de-embedded from the transients by least square fitting the curves with a numerical non-linear based finite differencing methodology (**Fig. 7 & 8**).

The Pulsed IV data signifies the presence of significant trap density for HEMTs grown on Silicon. The presence of a deep level trap with a large time constant (>1s) in the emission spectra for the devices on Silicon wafer, and corresponding correlating facts points to dislocations as the sources and can be considered as first quantitative and qualitative proof validating the proposed theory. Detailed results and analysis will be presented in the full length paper.

References

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[2] DiSanto, et.al., "Ozone passivation of slow transient current collapse in AlGaN⁄ GaN field-effect transistors: The role of threading dislocations and the passivation mechanism." Appl. phys. let. vol. 88 : 013504, 2006.

[3] Joh, Jungwo and Jesús A. Del Alamo. "A current-transient methodology for trap analysis for GaN high electron mobility transistors." *Electron Devices, IEEE Transactions on* vol. 58, nr. 1, p. 132-140, 2011.

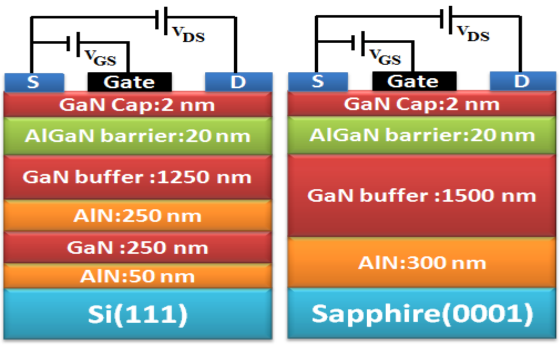

Fig. 1. Representative epitaxial structures of the HEMTs grown on Silicon and Sapphire.

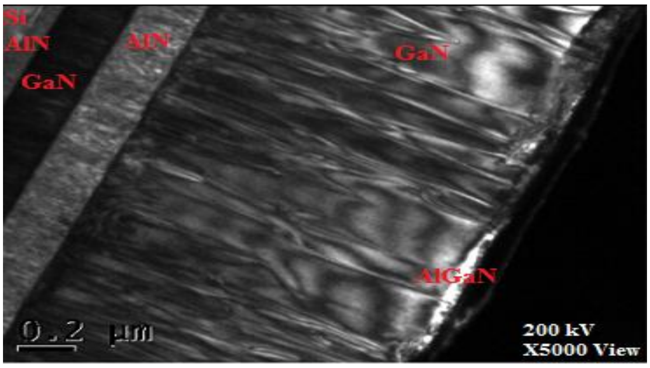

Fig. 2. Bright Field cross sectional imaging of the device layers grown on Silicon showing a dislocation density in the order of $10^{10}/cm^2$ (TEM image for Sapphire not shown)

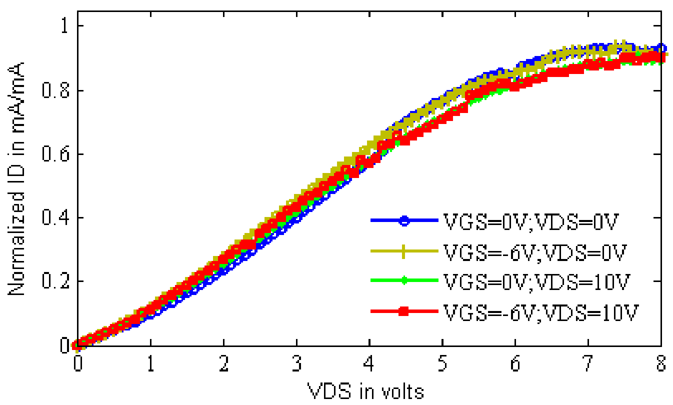

Fig. 3. Normalized Pulse IV data for the HEMT devices on Sapphire with 10% duty cycle probed from various bias points.

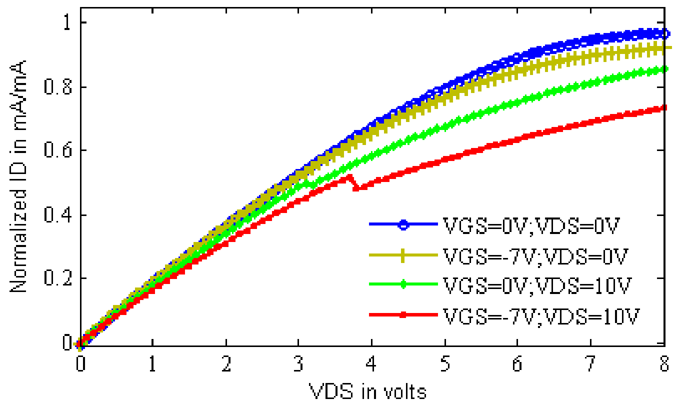

Fig. 4. Normalized Pulse IV data for the HEMT devices on Silicon with 10% duty cycle probed from various bias points.

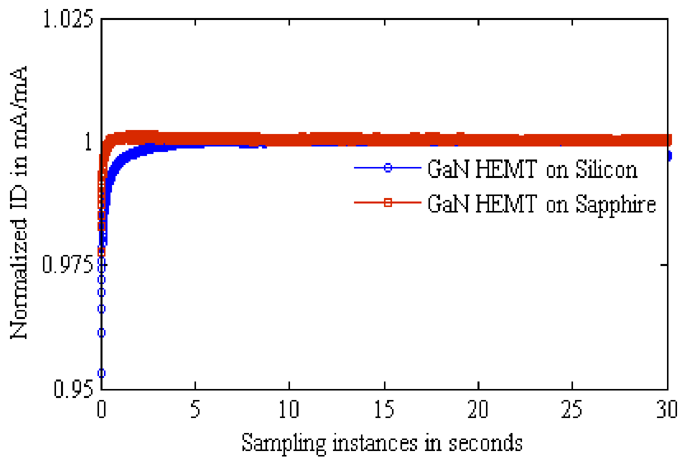

Fig. 5. Normalized current transient for HEMT devices sampled after a high on-state pulse.

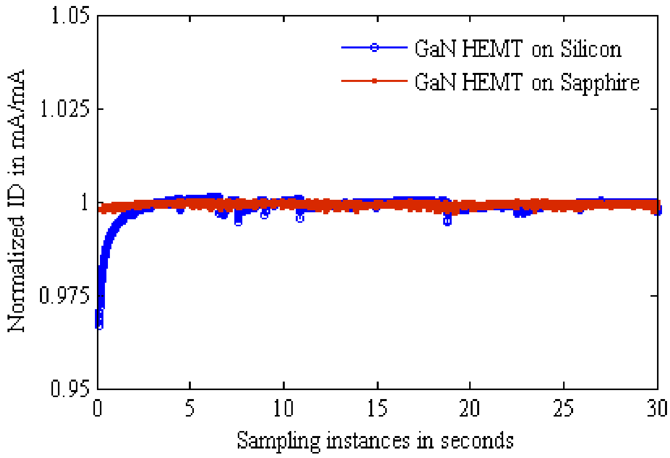

Fig. 6. Normalized current transient for HEMT devices sampled after a high on-state pulse.

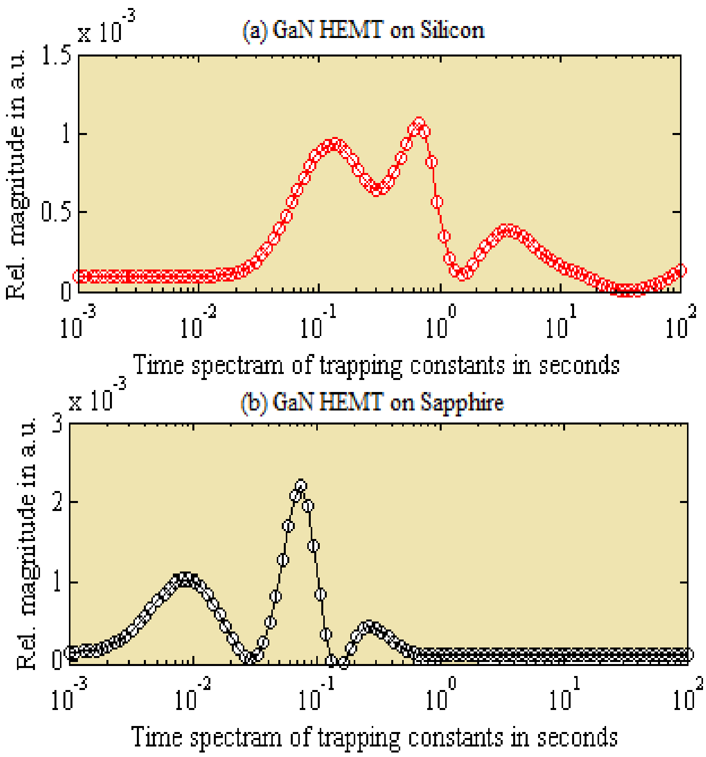

Fig. 7. Emission time constant spectra analyzed from transient after a high ON-state pulse.

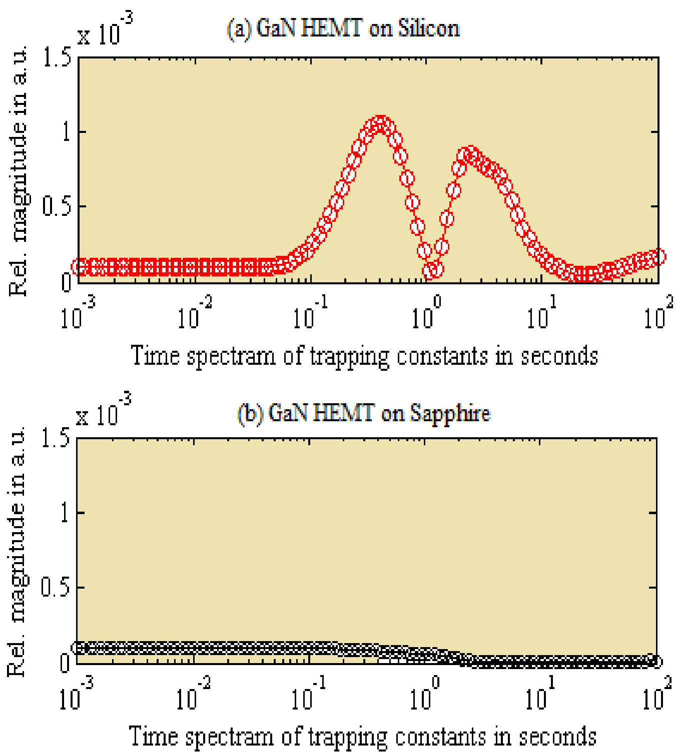

Fig. 8. Emission time constant spectra analyzed from transient after a deep OFF-state pulse.