Abstract #2543, Honolulu PRiME 2012, © 2012 The Electrochemical Society

Degradation Study of Single and Double-Heterojunction InAlN/GaN HEMTs by Two-Dimensional Simulation

V. Palankovski[1] and J. Kuzmik[1,2]
[1]AMADEA group, Inst. for Microelectronics, TU Wien, Gusshausstrasse 27-29, 1040 Vienna, Austria
[2]Inst. of Elec. Engineering, Slovak Academy of Sciences, Dubravska cesta 9, 84104 Bratislava, Slovakia
palankovski@iue.tuwien.ac.at

We study the concept of double-heterostructure quantum well (DHQW) InAlN/GaN/AlGaN high electron mobility transistor (HEMT) for higher device robustness and less degradation. Physics-based device simulation proves that the back barrier blocks the carrier injection into the device buffer. However, the energy of the injected electrons in the buffer is higher for any quantum well design in InAlN /GaN than in AlGaN/GaN HEMTs. This energy may be sufficient for releasing hydrogen from GaN point defects.

InAlN/GaN HEMTs are an excellent alternative to AlGaN /GaN HEMTs for ultra high-frequency [1,2] and power [3] applications. In this work, we address possible hot electron degradation of the buffer layer, which is one of the most critical issues for InAlN/GaN HEMTs [4]. For AlGaN/GaN HEMTs, it was shown that electrical stress at drain voltage V_{DS} =20V and gate voltage V_{GS} close to the pinch-off can reduce the transconductance and degrade the GaN buffer. The effect was explained by the high electric field giving sufficient energy (0.72eV-3.55eV) to electrons to dehydrogenate point defects in the buffer [5,6]. The changes are irreversible and can lead to a shift in the threshold voltage and to degraded channel mobility.

In recent work, $In_{0.17}Al_{0.83}N$(14nm)/GaN(1.2um) single quantum well (SQW) and novel $In_{0.17}Al_{0.83}N$(14nm)/GaN (50nm)/$Al_{0.04}Ga_{0.96}N$(310nm)/GaN(1.2um) DHQW HEMT structures were degraded by applying off-state stress [7]. Three orders of magnitude reductions in gate and drain off-state leakage currents in DHQW when compared with those of the SQW HEMT were observed [7]. The gate length is 250nm, and the gate-to-drain distance is 1.5um. We performed hydrodynamic simulations with our two-dimensional device simulator Minimos-NT, which is well-suited for numerical analysis of GaN HEMTs [8], to evaluate hot-electron injection effects in the buffer. In particular, we analyzed why InAlN/GaN HEMTs seem to be more vulnerable to off-state stress than their AlGaN/ GaN counterparts. We compared simulation results for the experimental SQW and DHQW $In_{0.17}Al_{0.83}N$/GaN HEMTs [7] and for a hypothetical $Al_{0.22}Ga_{0.78}N$/GaN HEMT. 22nm $Al_{0.22}Ga_{0.78}N$ layer thickness is chosen, so that all devices share the same geometries and threshold voltage of -6.8V.

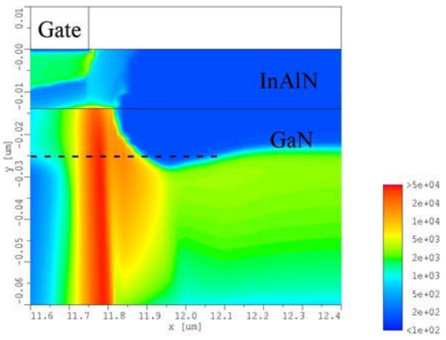

Fig.1 Calculated two-dimensional electron temperature maps [K] at the drain side of the gate in DHQW HEMT.

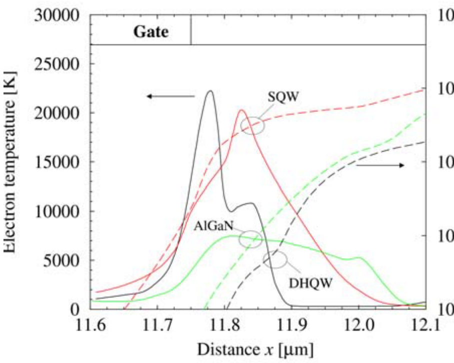

Fig.2 Cross sections of the electron concentration (dashed lines) and temperature (solid lines) in AlGaN /GaN (green color) SQW, InAlN/GaN SQW (red), and DHQW (black) HEMTs at V_{GS} =-8V and V_{DS} =20V. The position of the cross sections along the GaN channel at a distance 11 nm from the QW is marked with dashed line in Fig.1.

For example, Fig.1 shows the electron temperature (T_n) distribution near the drain side of the gate in the DHQW HEMT. Our results for V_{GS} =-8V and V_{DS} =20V indicate much higher energies of electrons injected in the buffer layer of the InAlN/GaN than in AlGaN/GaN HEMTs. In particular, the “hot spot” in the buffer of the AlGaN/GaN HEMT reaches T_n~7000K (corresponding to ~0.95eV) in comparison with T_n ~20000K for the InAlN/GaN HEMTs (see Fig.2). The indicated T_n in AlGaN/GaN corresponds only to the onset of a possible dehydrogenation of defects, which has a minimum required energy of ~0.7eV. On the other hand, hot electrons in the InAlN/GaN HEMT buffer seem to have sufficient energy for releasing H^+ atoms, i.e. it is more vulnerable to degradation. The higher T_n is due to the higher polarization fields in InAlN/GaN than in AlGaN/GaN HEMTs, which require the application of a sufficient gate bias to deplete the channel. The resulting vertical electric field in InAlN/GaN HEMTs in off-state deflects the channel electrons with higher energies in the buffer. Furthermore, we compared SQW and DHQW InAlN/GaN HEMTs (see Fig.2). The peak T_n is not much affected by the presence of the AlGaN back barrier, however, as indicated by the lateral cross sections (Fig.2), there is a much lower concentration of injected electrons in the DHQW than in the SQW HEMT. This may explain the higher stability of the DHQW InAlN/ GaN HEMTs. Moreover, besides the blocking effect of the back barrier on the injection of hot electrons, the negative polarization charges at the GaN/AlGaN raise the conduction band in the GaN channel, which increases the T_n required for the dehydrogenation of point defects [9]. This study was performed on unpassivated devices. Investigations of degradation in passivated DHQW HEMTs are ongoing.

Support from the Austrian Science Fund (FWF) and the Slovak R&D Agency is acknowledged.

[1] D.S. Lee *et al.*, *IEEE Elec.Dev.Lett.* 32 (2011) 755.
[2] H. Sun *et al.*, *IEEE Elec.Dev.Lett.* 31 (2010) 957.
[3] N. Sarazin *et al.*, *IEEE Elec.Dev.Lett.* 31 (2010) 11.
[4] J. Kuzmik *et al.*, *J.Appl.Phys*. 106 (2009) 124503.
[5] T. Roy *et al.*, *Appl.Phys.Lett.* 96 (2010) 133503.
[6] Y. Puzyrev *et al.*, *J.Appl.Phys.* 109 (2011) 034501.
[7] J. Kuzmik *et al.*, *Jpn.J.Appl.Phys.* (2012) in print.
[8] S. Vitanov *et al.*, *IEEE Tran.Elec.Dev.* 59 (2012) 685.
[9] A.F. Wright, *J.Appl.Phys.* 90 (2001) 1164.