Theoretical Comparison of $Al_XGa_{1-X}N$ (x =0.2 and 0.4)/ GaN HJFETs Based on Full Band Monte Carlo Simulation

Y. Ando, W. Contrata, H. Miyamoto, K. Matsunaga, M. Kuzuhara,
K. Kunihiro*, K. Kasahara*, T. Nakayama*, N. Hayama*, Y. Takahashi*, Y. Ohno*
Photonic and Wireless Devices Research Laboratories, NEC Corporation
2-9-1 Seiran, Otsu 520-0833 JAPAN
* 34 Miyukigaoka, Tsukuba 305-8501 JAPAN
TEL: +81-77-537-7684 FAX: +81-77-537-7689 e-mail: y-ando @bp.jp.nec.com

A high Al content AlGaN/ GaN (x_{Al} >0.3) heterojunction FET (HJFET) has demonstrated state-of-the-art power density [1]. One of the most powerful tools to describe high-field transport is the full band Monte Carlo (FBMC) technique [2], [3]. However, this technique has not yet been applied for AlGaN/ GaN HJFETs. In this work, 2-D FBMC simulation including realistic band structures of wurtzite GaN and AlGaN was performed to study Al composition dependence of performance for AlGaN/ GaN HJFET.

The equation of motion of electrons was solved by FBMC technique, simultaneously with the 2-D Poisson's equation. Simulated device is a recessed gate AlGaN (x_{Al} =0.2 and 0.4)/ GaN HJFET (Lg =0.1- 0.9 μm). The gate-source and gate-drain separations were scaled in proportion to Lg. The polarization charge (σ) due to the piezoelectric and spontaneous effects was introduced at top and bottom interfaces of AlGaN as fixed charges. As x_{Al} increases, σ is enhanced and the same threshold voltage may be obtained by reducing the AlGaN layer thickness (t_{AlGaN}). In this simulation, t_{AlGaN} was set at 40 and 20 nm for x_{Al} =0.2 and 0.4, respectively, both of which are less than the critical layer thicknesses.

For x_{Al} =0.4, not only due to the thinner barrier, but also due to the enhanced carrier density, carrier confinement improves and short channel effect is reduced. As a result, Imax and gm improvements with reducing Lg were found to be more significant for x_{Al} =0.4. Calculated intrinsic f_T (~160 GHz for Lg =0.1 μm) was almost the same between x_{Al} =0.2 and 0.4, but due to improved gm, the extrinsic f_T is expected to be higher for x_{Al} =0.4. The off-state breakdown voltage BVds was predicted according to the avalanche breakdown condition, in which each electron causes a single impact ionization on average before reaching the drain. Predicted BVds was 300 (60) V for Lg =0.9 (0.1) μm, and it hardly depends on x_{Al}. On the other hand, due to increased Imax, the maximum linear output power Pmax =(1/8)×Imax×BVds improves as x_{Al} increases especially for small Lg. Estimated Pmax for x_{Al} =0.4 was 53 (26) W/mm for Lg =0.9 (0.1) μm. In summary, the effect of x_{Al} was predicted to be more significant for small Lg. The high Al content and short gate length AlGaN/ GaN HJFET is promising for use in millimeter-wave power applications. Also, these results indicate a wide margin for future improvements over current power density (~10 W/mm).

This work was performed as a part of the Regional Consortium Program supported by NEDO.

References

[1] Y. F. Wu et al., *Proc. IEDM '99*, 925.
[2] J. Kolnik *et al.*, *J. Appl. Phys.* **78**, 1033 (1995).
[3] M. Farahmand and K. F. Brennan, *IEEE Trans. Electron Device* **46**, 1319 (1999).
[4] B. E. Foutz, *et al.*, *J. Appl. Phys.* **85**, 7727 (1999).

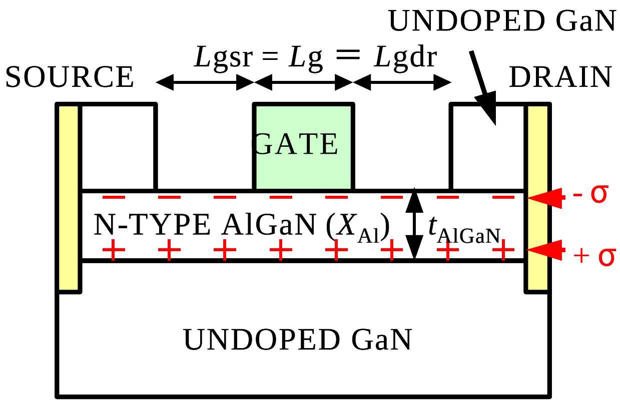

Fig. 1. Simulated AlGaN/ GaN HJFET srtructure.

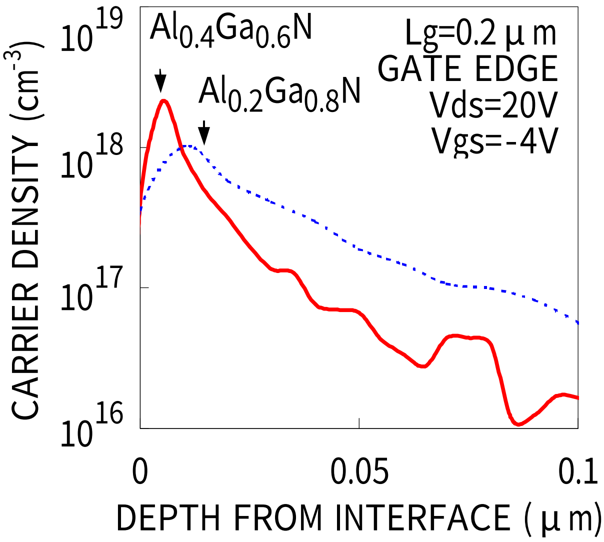

Fig. 2. Carrier density profile at the drain edge of gate.

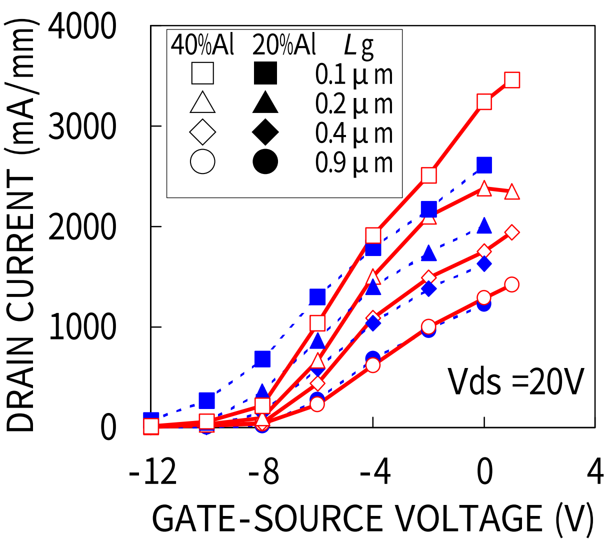

Fig. 3. *Id* vs. *V*gs (*V*ds=20V).

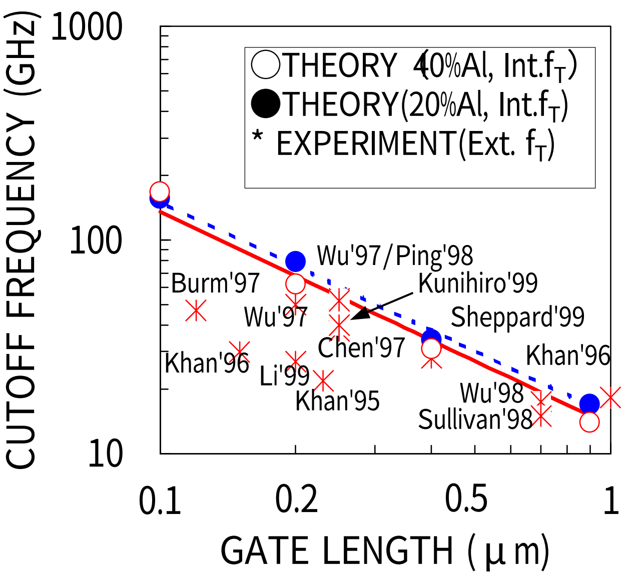

Fig. 4. Intrinsic f_T vs. *Lg*

(*: Measured extrinsic f_T from the literature).

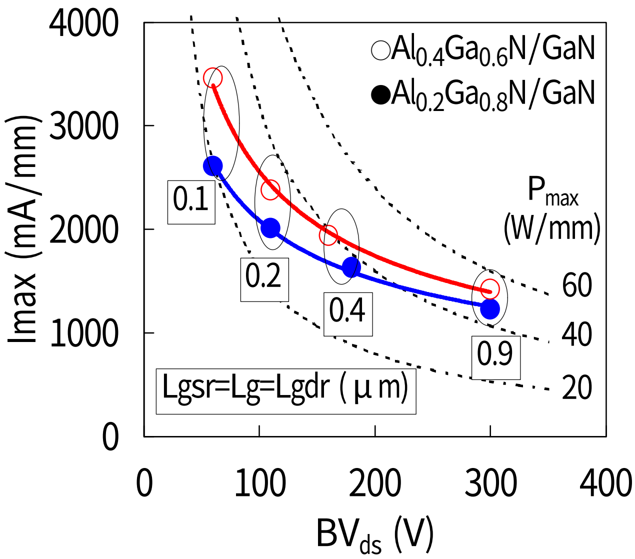

Fig. 5. *I*max vs. *BV*ds

(⋯: Constant *P*max contour).