D-7-01 Extended Abstracts of the 2020 International Conference on Solid State Devices and Materials, VIRTUAL conference, 2020, pp243-244

Large Signal Results at 6 GHz and record f_t/f_{max} for AlN/GaN/AlN HEMTs

A. Hickman[1*], R. Chaudhuri[1], L. Li[1], K. Nomoto[1], J. C. M. Hwang[2], H. G. Xing[1,2,3], D. Jena[1,2,3,4]
[1]Electrical and Computer Engineering, [2]Material Science and Engineering, [3]Kavli Institute, [4]Applied and Engineering Physics, Cornell University, Ithaca, NY, USA
contact: alh288@cornell.edu,

Abstract: In this work, we report record f_t/f_{max} product of 130/262 GHz, as well record output power and power added efficiency (PAE) of 3.5 W/mm and 30% at 6 GHz for the AlN/GaN/AlN HEMT. **This early report of output power/PAE, combined with excellent on-current and f_t/f_{max}, demonstrates the exciting potential for HEMTs on the AlN platform to enable the next generation of high-power, mm-wave communication.**

Next-generation (6G) wireless communication and high-resolution radar systems target high-power operation in the terahertz regime. Gallium nitride high-electron-mobility transistors (GaN HEMTs) are well-suited for this high-power, high-frequency application. However, the conventional AlGaN/GaN heterostructure provides poor confinement of the two-dimensional electron gas (2DEG), generating short channel effects at high frequencies. Additionally, its RF power performance is limited by the breakdown voltage.

To overcome these limitations, a HEMT based on aluminum nitride (AlN) was proposed [1]. The heterostructure incorporates a GaN channel between an AlN buffer and an AlN top barrier. AlN offers material and device design advantages over the conventional AlGaN/GaN HEMT. The AlN buffer provides confinement of the 2DEG, and increases the polarization offset with GaN, inducing higher density 2DEGs for much thinner top barriers (5 nm). The AlN top barrier maximizes the bandgap, improving the breakdown voltage of the HEMTs [2].

In this work, we report record f_t/f_{max} product, as well record output power and power added efficiency (PAE) at 6 GHz for the AlN/GaN/AlN HEMT. A 2 nm GaN passivation layer / 5 nm AlN barrier / 200 nm GaN channel / 350 nm AlN buffer structure was grown on a 6H Silicon Carbide substrate using Molecular Beam Epitaxy (MBE). Hall-effect measurements at room temperature revealed a 2DEG sheet concentration of $3 \cdot 10^{13}$ cm^{-2}, electron mobility of 711 $cm^2/V{\cdot}s$, and sheet resistance of 293 Ω/☐. Heavily n-type (10^{20} cm^{-3} Si doping) GaN ohmic contacts were regrown using MBE, resulting in a contact resistance of 0.39 Ω·mm. T-gates (Ni/Au, 50/200 nm) were defined via electron beam lithography, with gate lengths ranging from 45-90 nm. The devices were passivated with 40 nm of silicon nitride to minimize DC-RF dispersion.

The devices demonstrated on-currents of 2 A/mm with an on-resistance of 1 Ω·mm and excellent saturation. Transfer characteristics revealed I_{on}/I_{off} ratio of 10^3 and peak transconductance of 0.5 S/mm. Pulsed I_DV_D measurements showed a dispersion of 15%. Bias-dependent S-parameters were measured in the range of 0.05-40 GHz, across a range of drain and gate biases. The extracted peak of **f_t/f_{max} = 130/262 GHz** (L_G=90 nm) is the highest f_t/f_{max} product reported on the AlN platform.

Large-signal measurements were performed at 6 GHz using a passive load-pull system. A device biased in Class AB ($V_{DS,Q}$ = 20 V, $I_{DS,Q}$ = 500 mA/mm) demonstrated **P_{out} = 3.5 W/mm with an associated PAE = 30%**. This early report of output power/PAE, combined with excellent on-current and f_t/f_{max}, demonstrates the exciting potential for HEMTs on the AlN platform to enable the next generation of high-power, mm-wave communication.

[1] G. Li, R. Wang, J. Guo, J. Verma, Z. Hu, Y. Yue, F. Faria, Y. Cao, M. Kelly, T. Kosel, H. G. Xing, D. Jena, *IEEE Electron Device Lett.*, vol. 33, no. 5, pp. 661-663, May 2012.
[2] A. Hickman, R. Chaudhuri, S. J. Bader, K. Nomoto, K. Lee, H. G. Xing, and D. Jena, *IEEE Electron Device Lett.*, vol. 40, no. 8, pp. 1293–1296, Aug. 2019.

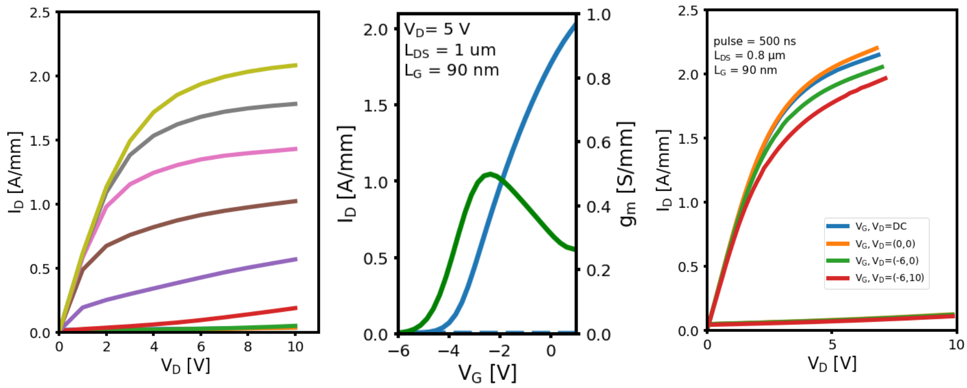

Figure 1: (a) Output characteristics of an AlN/GaN/AlN HEMT demonstrating 2 A/mm. (b) Transfer characteristics with g_m = 0.5 S/mm. (c) Pulsed I_DV_D characteristics showing a dispersion of 15% when pulsed at 500 ns for V_G = 0 V and -6 V.

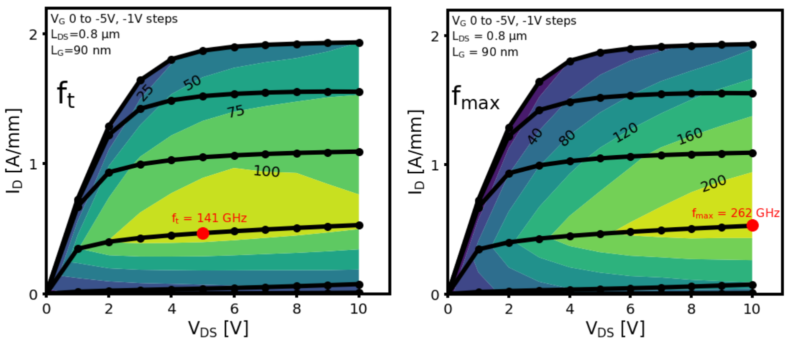

Figure 2: The extracted (a) f_t and (b)f_{max} characteristics across a range of gate and drain biases. The f_t/f_{max} combination of 130/264 at VG, VD = -4, 10 V, is the highest for devices on the AlN platform.

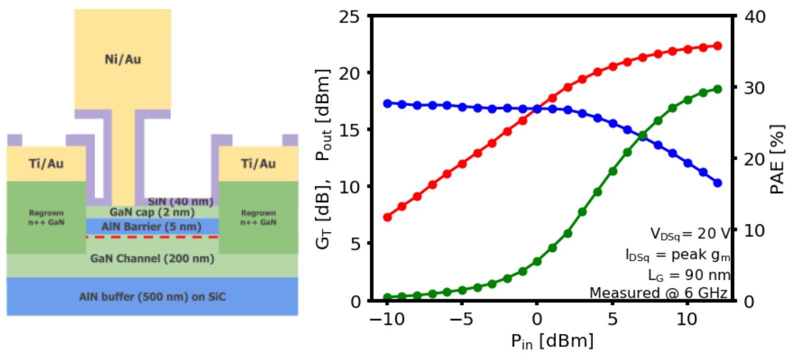

Figure 3: (a) Cross-sectional representation of a processed AlN/GaN/AlN HEMT. (b) Large signal measurements performed with passive load-pull at 6 GHz, showing an output power of 3.5 W/mm at a power added efficiency of 30%.