MBE Grown AlScN/AlN/GaN High Electron Mobility Transistors with Regrown Contacts

CNF Project Number: 2438-16

Principal Investigator(s): Huili Grace Xing, Debdeep Jena

User(s): Kazuki Nomoto

Affiliation(s): School of Electrical and Computer Engineering, Cornell University

Primary Source(s) of Research Funding: DSSP/ASCE

Contact: grace.xing@cornell.edu, kn383@cornell.edu

Primary CNF Tools Used: Autostep i-line Stepper, Heidelberg Mask Writer - DWL2000, P7 Profilometer, FilMetrics, AFM Veeco Icon, Zeiss SEM, PT 770, Oxford 81, Oxford ALD / PECVD, SC4500 Evaporators, AJA Sputter Deposition, RTA AG610, JEOL 9500

Abstract:

We report the first observation of ferroelectric gating in AlScN barrier wide-bandgap nitride transistors. These FerroHEMT devices realized by direct epitaxial growth represent a new class of ferroelectric transistors in which the semiconductor is itself polar, and the crystalline ferroelectric barrier is lattice-matched to the substrate. The FerroHEMTs reported here use the thinnest nitride high-K and ferroelectric barriers to date to deliver a high on-currents at 1.34 A/mm, and highest speed AlScN transistors with f_{MAX} > 150 GHz observed in any ferroelectric transistor. The FerroHEMTs exhibit hysteretic I_d-V_{gs} loops with subthreshold slopes below the Boltzmann limit. A control AlN barrier HEMT exhibits neither hysteretic nor sub-Boltzmann behavior. While these results introduce the first epitaxial high-K and ferroelectric barrier technology to RF and mm-wave electronics, they are also of interest as a new material platform for combining memory and logic functionalities in digital electronics.

Summary of Research:

The $GaN/Al_{0.86}Sc_{0.14}N/AlN/GaN$ HEMT structure consists of a 2 nm GaN cap layer, a 5 nm $Al_{0.86}Sc_{0.14}N$ barrier, a 2 nm AlN spacer (total barrier thickness: 9 nm), a 1000 nm unintentionally doped GaN channel, and AlN nucleation layer on a SiC substrate, grown by plasma assisted molecular beam epitaxy (PA-MBE). Room temperature Hall-effect measurements with In-dots prior to device fabrication showed a 2DEG sheet concentration of $2.99 \times 10^{13}/cm^2$ and electron mobility of 500 $cm^2/V{\cdot}s$, corresponding to a sheet resistance of 417 Ω/sq.

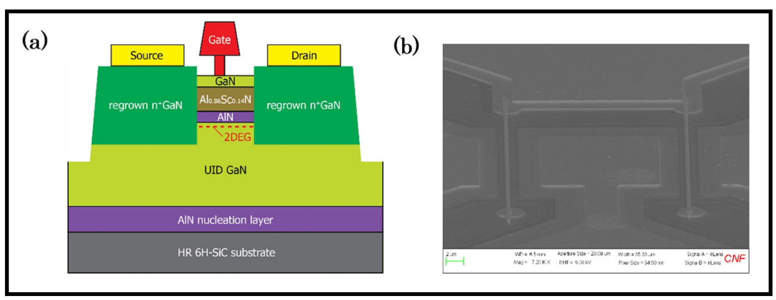

Figure 1: (a) Schematic cross-section and (b) SEM image of AlScN/AlN/GaN HEMTs on 6H-SiC with regrown n^+GaN contacts.

A schematic cross-section of the AlScN/AlN/GaN HEMT device with regrown n^+ GaN contacts is shown in Figure 1(a). The device fabrication process started with patterning of a SiO_2/Cr mask for n^+GaN ohmic regrowth by PA-MBE. The pre-regrowth etch depth into the HEMT structure was 40 nm, and regrown n^+GaN was 100 nm with a Si doping level of $7 \times 10^{19}/cm^3$. Non-alloyed ohmic contact of Ti/Au was deposited by e-beam evaporation. T-shaped Ni/Au (30/350 nm) gates were formed by e-beam lithography, followed by liftoff. TLM measurements yielded a contact resistance of 0.31 Ω·mm.

The device presented here has a regrown n^+GaN source-drain distance L_{SD} of 600 nm, a gate width of 2 × 25 µm, and a gate length L_G of 90 nm. An SEM image of completed AlScN/AlN/GaN HEMT is shown in Figure 1(b).

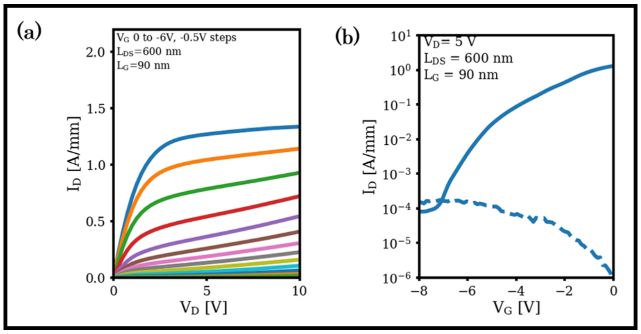

Figure 2: (a) Family I-V curves and (b) transfer characteristics of the device with L_G = 90 nm and L_{SD} = 600 nm.

Figure 2(a) shows the family I-V curves of the device, measured for V_{DS} = 0 to 10 V and V_{GS} = 0 to -6 V. The device has a saturation drain current I_{DSS} = 1.34 A/mm and an on-resistance R_{ON} = 1.4 Ω·mm extracted at V_{gs} = 1 V. The transfer curves are shown in Figure 2(b). A peak extrinsic transconductance g_m is 0.46 S/mm at V_{DS} = 5 V.

Figure 3(a) shows the current gain $|h_{21}|^2$ and unilateral gain U of the device as a function of frequency at the peak f_T bias condition, V_{DS} = 10 V, and V_{GS} = -1.4 V.

The extrapolation of both $|h_{21}|^2$ and U with -20 dB/dec slope gives the current gain cutoff frequency/maximum oscillation frequency f_T / f_{MAX} of 78/156 GHz after de-embedding. The f_T and f_{MAX} of the device are summarized in Figure 3(b), showing how the results of this device compare with the early state-of-art results of AlScN/GaN HEMTs on SiC substrates [1-3].

This work was supported by the DARPA DSSP program monitored by Dr. Tom Kazior. This work was also supported, in part, by NSF DMREF Grant No. 1534303, Cornell NanoScale Facility (Grant No. NNCI-2025233), AFOSR Grant No. FA9550-20-1-0148, NSF Grant No. DMR-1710298, and the CCMR Shared Facilities, which are supported through the NSF program.

References:

[1] T. E. Kazior, et al., 2019 IEEE/MTT-S International Microwave Symposium (2019).

[2] A. J. Green, et al., IEEE Electron Device Letters, Vol. 40, No. 7, July (2019).

[3] J. Cheng, et al., IEEE Transactions on Electron Devices, Vol. 68, No. 7, July (2021).

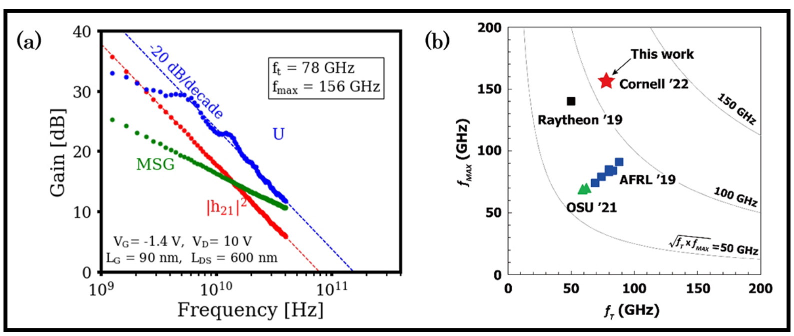

Figure 3: (a) Current gain and unilateral gain of the device with L_g = 90 nm, showing f_T / f_{MAX} = 78/156 GHz. (b) Comparison of the measured f_T and f_{MAX} of $Al_xSc_{1-X}N$/GaN HEMTs.