Fully Passivated InAlN/GaN HEMTs on Silicon with f_T/f_{MAX} of 144/141 GHz

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Primary CNF Tools Used: Autostep i-line stepper, Heidelberg mask writer DWL2000, P7 profilometer, FilMetrics, AFM Veeco Icon, Zeiss SEM, PT770, Oxford81, Oxford PECVD, Oxford ALD, odd-hour evaporator, AJA sputter deposition, RTA AG610, JEOL9500

Abstract:

Depletion-mode high-electron mobility transistors (HEMTs) based on a quaternary barrier $In_{0.17}Al_{0.83}N$/AlN/GaN heterostructure on a Si substrate were fabricated. The 87 nm long gate device shows a dc drain current density of 2.48 A/mm, a peak extrinsic transconductance of 450 mS/mm, and balanced current gain cutoff frequency f_T and maximum oscillation frequency f_{MAX} are 144 and 141 GHz, respectively.

Summary of Research:

Gallium nitride (GaN)-based high electron mobility transistors (HEMTs) have demonstrated great potential for high-speed, high power RF applications [1] and next-generation power electronics [2]. In addition, the adoption of a Si substrate would pave the way for low cost and high-performance GaN electronics.

We report the fabrication and DC and RF characteristics of fully passivated InAlN/GaN high-electron mobility transistors (HEMTs) on Si substrates with balanced f_T and f_{MAX} (144/141 GHz).

The InAlN/AlN/GaN HEMT structure consists of a 10 nm $In_{0.17}Al_{0.83}N$ barrier, a 1 nm AlN spacer (total barrier thickness: 11 nm), a 800 nm unintentionally doped GaN channel, and AlGaN/AlN buffer and nucleation layers on a 6" Si substrate, grown by a Propel® HVM MOCVD system at Veeco Instruments. Room temperature Hall-effect measurements prior to device fabrication showed a 2DEG sheet concentration of $2.4 \times 10^{13}/cm^2$ and electron mobility of 1310 $cm^2/V \cdot s$, corresponding to a sheet resistance of 196 Ω/sq.

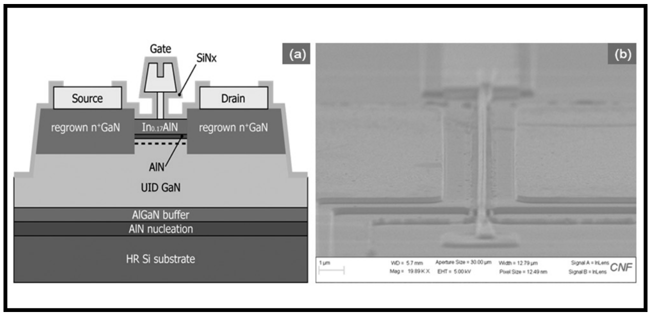

Figure 1: (a) Schematic cross-section of fully passivated InAlN/AlN/GaN HEMTs on Si with regrown n+GaN contacts. (b) An angled SEM image of a fabricated InAlN/AlN/GaN HEMT with an EBL T-gate.

A schematic cross-section of the InAlN/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 mask for n^+GaN ohmic regrowth by PA-MBE. The preregrowth 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/Ni was deposited by e-beam evaporation. T-shaped Ni/Au (40/200 nm) gates were formed by electron-beam lithography, followed by liftoff. The devices were finally passivated by a 50 nm PECVD SiN_x. TLM measurements yielded a contact resistance of 0.19 Ω·mm. The device presented here has a regrown n^+GaN source-drain distance L_{sd} of 800 nm, a gate width of 2×25 µm, and a gate length L_g of 87 nm. Figure 1(b) shows an angled-SEM image of the fabricated InAlN/AlN/GaN HEMT.

Figure 2(a) shows the family *I-V* curves of the device, measured for V_{ds} = 0 to 8 V and V_{gs} = 1 to -8 V. The device has a saturation drain current I_{dss} = 2.48 A/mm and an on-resistance R_{on} = 1.07 Ω·mm extracted at V_{gs} = 1 V. The transfer curves are shown in Figure 2(b). A peak extrinsic transconductance g_m is ~ 0.45 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} = 5 V, and V_{gs} = -4.6 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 144/141 GHz after de-embedding. The f_T and f_{MAX} of the device are summarized in Figure 3(b). Figure 3(b) shows how the results of this device compare with the early state-of-art results of GaN HEMTs on Si substrates [3,4].

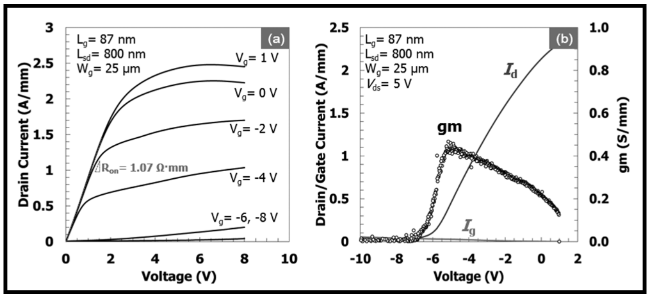

Figure 2: (a) Family I-V curves and (b) transfer characteristics of the device with L_g *= 87 nm and* L_{sg} *= 800 nm.*

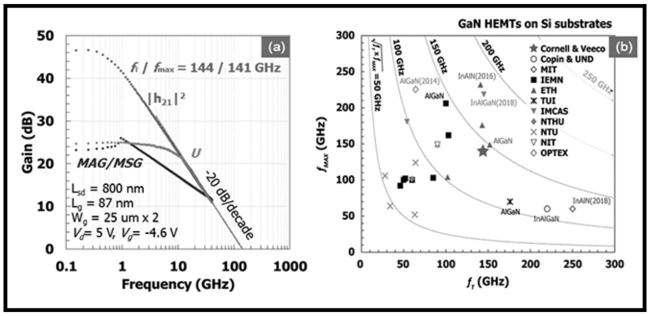

Figure 3: (a) Current gain and unilateral gain of the device with L_g *= 87 nm, showing* f_T */* f_{MAX} *= 144/141 GHz. (b) Comparison of the measured* f_T *and* f_{MAX} *of GaN HEMTs on Si substrates.*

References:

[1] Y. Yue, et al., “InAlN/AlN/GaN HEMTs with regrown ohmic contacts and f_T of 370 GHz,” IEEE Electron Device Lett., vol. 33, no. 7, pp. 988-990, Jul. 2012.

[2] M. Zhu, et al., “1.9-kV AlGaN/GaN lateral Schottky barrier diodes on silicon,” IEEE Electron Device Lett., vol. 36, no. 4, pp. 375-377, Apr. 2015.

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[4] W. Xing, et al., IEEE EDL, Vol. 39, No. 1, 75-78 (2018).