First high-frequency noise report of InAlN barrier HEMTs on silicon

Singapore researchers present a good candidate for low-noise and high-linearity receiver circuit applications.

Researchers in Singapore have reported high-frequency performance of gallium nitride (GaN) indium aluminium nitride (InAlN) high-electron-mobility transistors (HEMTs) on silicon substrates, including the first noise measurements [S. Arulkumaran et al, IEEE Electron Device Letters, published online 13 August 2014]. The team from Nanyang Technological University and the A*STAR (Agency of Science, Technology and Research) organization believe such devices are good candidates for low-noise and high-linearity receiver circuit applications.

The product of the unilateral power gain cut-off and gate length is the "highest ever reported for InAlN/GaN HEMT on silicon substrate", according to the researchers. Alternative substrates for GaN HEMTs are silicon carbide (SiC) or sapphire.

The HEMT heterostructures were grown on high-resistivity silicon (111) substrates using metal-organic chemical vapor deposition (MOCVD). The nucleation layer of 100nm AlN was followed by a 1000nm GaN buffer, 1nm AlN spacer and 9nm $In_{0.17}Al_{0.83}N$ barrier. The InAlN composition gives a lattice match to that of GaN. The InAlN/AlN/GaN interface results in a two-dimensional electron gas (2DEG) channel in the GaN buffer with mobility of $759cm^2/V\text{-}s$ and carrier concentration of $2.74x10^{13}/cm^2$.

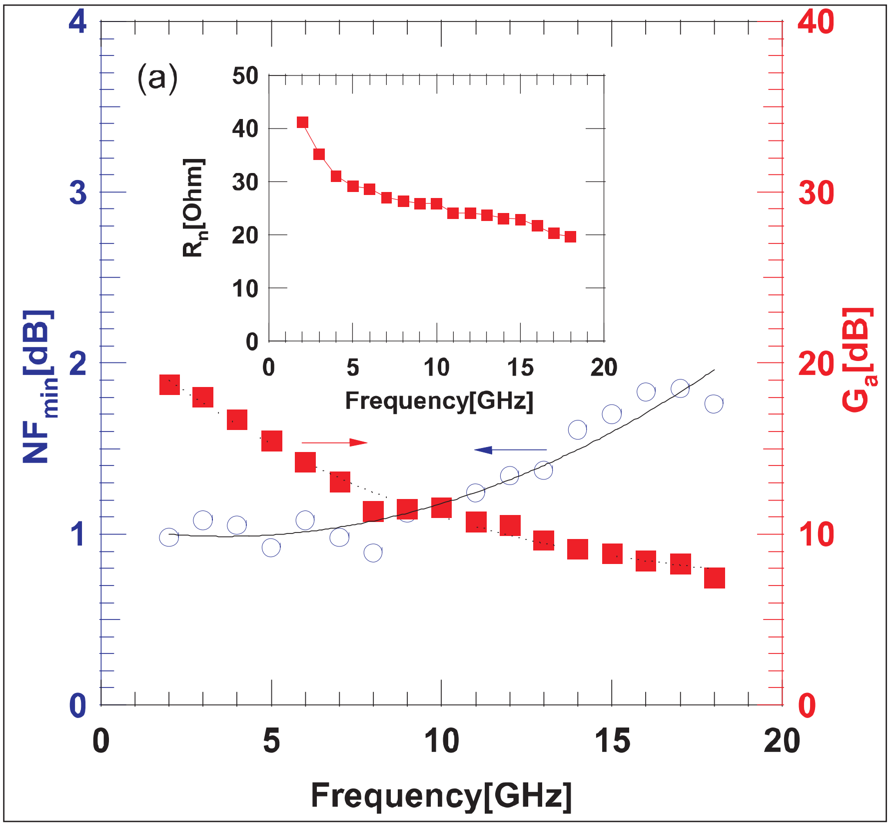

Figure 1. (a) NF_{min} and G_a versus frequencies (2–18 GHz).

HEMT fabrication began with mesa isolation through a plasma etch process. The ohmic contacts consisted of annealed titanium/aluminium/nickel/gold. The T-gate of nickel/gold had a 0.17μm footprint/gate length (L_g) and 0.5μm head. The gate width was 2x75μm. The source–gate and gate–drain separations were 0.8μm and 1.7μm, respectively. Passivation was provided by plasma-enhanced chemical vapor deposition (PECVD) of silicon nitride.

The maximum current density of the device was 1320mA/mm at 1V gate potential. The maximum extrinsic transconductance was 363mS/mm. The researchers comment: "The observed current density is almost double than that of similar AlGaN-barrier thick GaN HEMTs (800mA/mm)."

In frequency measurements, the cut-off (f_T) was found to be 64GHz at −2.4V gate and 6V drain biases. The unilateral power gain cut-off ($f_{max}(U)$) was 72GHz. The maximum stable gain $f_{max}(MSG)$ was 106GHz. The researchers add: "The product $f_{max}(U)xL_g$=12.24GHz-μm is the highest ever reported for InAlN/GaN HEMT on Si substrate." In InAlN-barrier HEMTs on silicon carbide, a product of 25GHz-μm has been achieved, possibly due to better 2DEG mobility or lower parasitic effects.

Noise performance was measured between 2GHz and 18GHz with a drain bias of 4V and gate potential of −2.25V (Figure 1). The minimum noise figure (NF_{min}) measurements at 10GHz and 18GHz were 1.16dB and 1.76dB, respectively. The corresponding associated

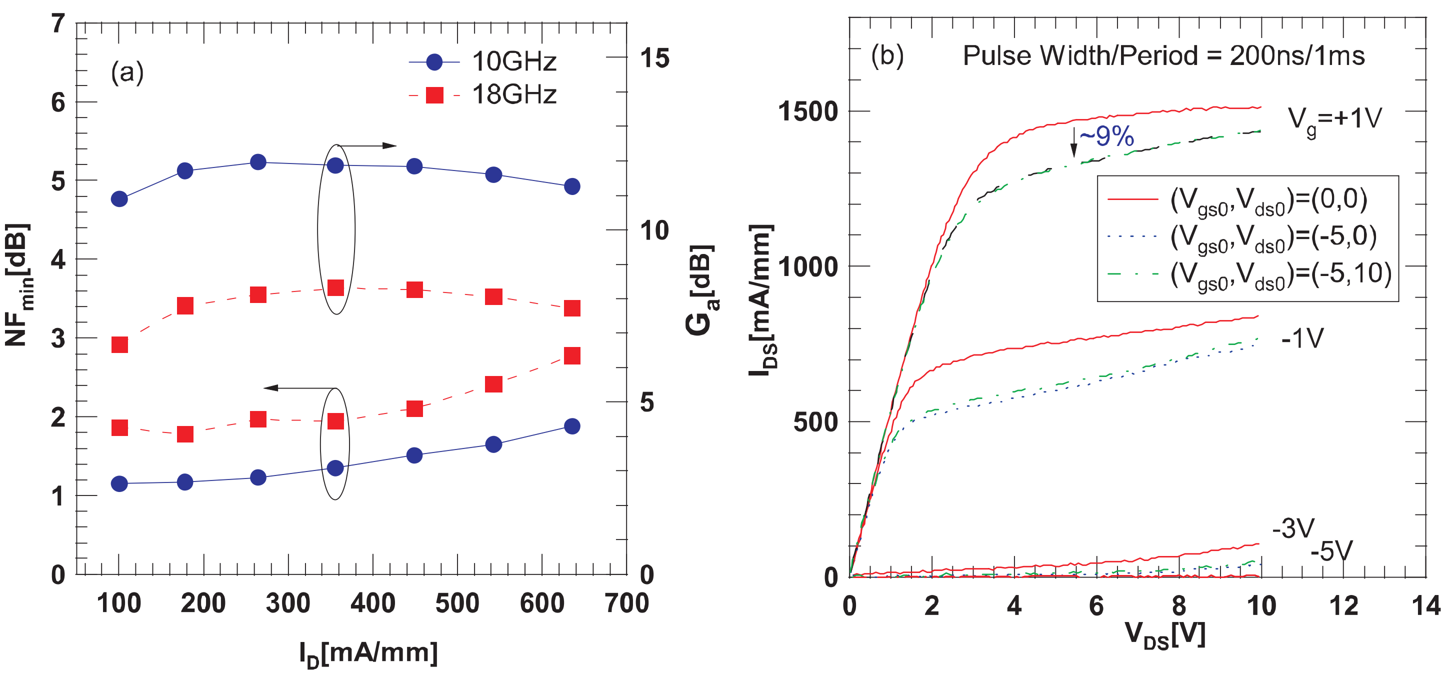

Figure 2. (a) Variation of NF$_{min}$ and G$_a$ over drain current (I$_D$) at 10GHz and 18GHz. (b) Pulsed drain–source current–voltage (I$_{DS}$–V$_{DS}$) characteristics for InAlN/GaN HEMTs on silicon substrate.

gain (G$_a$) readings were 11.54dB and 7.5dB. The researchers write: "The obtained NF$_{min}$ at 10GHz and 18GHz are comparable to the reported values for AlGaN/GaN on Si substrate with the same gate length. The measured NF$_{min}$ of our devices at 18GHz is comparable to the NF$_{min}$ of InAlN/GaN on SiC and AlN/GaN on Si substrate (see Table 1)."

In the lower-frequency 2-8GHz range the Singapore device demonstrated slightly high NF$_{min}$ values and some variation in performance that could be attributed to shot-noise effects from the gate leakage currents associated with the Schottky-based gate structure. Metal-insulator-semiconductor gate stacks would reduce leakage, hopefully reducing the noise in this lower range.

The noise figure variation (NF$_{min(low)}$ − NF$_{min(high)}$)/(I$_{DS(max)}$−I$_{DS(min)}$) of 1.36dB-mm/A at 10GHz and 1.67dB-mm/A at 18GHz over the drain current range 100mA/mm-636mA/mm was smaller than found by other groups producing AlN/GaN HEMTs and AlGaN/GaN HEMTs with similar gate lengths on silicon substrate (Figure 2). However, short-gate InAlN/GaN HEMTs on SiC show smaller variation, due presumably to the use of field plates and ohmic contact re-growth to reduce access resistance.

The researchers also assessed current collapse under gate-lag and drain-lag pulsed bias conditions. The collapse was 9% in both cases. The researchers say that the gate-lag current collapse is better and the drain-lag collapse is comparable to previously reported measurements on InAlN/GaN HEMTs on sapphire substrates. The reduced collapse effect is related to the lattice-matched InAlN barrier and optimized silicon nitride passivation, according to the team. ■

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Table 1.

Affiliation	HEMT structure	L$_g$(μm)	NF$_{min}$(dB) @10(18)GHz	(NF$_{min(low)}$ − NF$_{min(high)}$)/(I$_{DS(max)}$−I$_{DS(min)}$) @10GHz (dB-mm/A)
UIUC	AlGaN/GaN on SiC	0.25	0.75 (0.98)	−1.25
IEMN	AlGaN/GaN on Si	0.17	1.1 (1.8)	−14.4
Renesas	AlGaN/GaN/AlGaN on Si	0.16	0.78 (-1.2)	—
ETH-Z	InAlN/GaN on SiC	0.10	0.62 (1.5)	—
CNRS	InAlN/GaN on SiC	0.15	0.8 (1.8)	−1.18
Triquint	InAlN/GaN on SiC	0.05	0.3	−0.74
NTU	AlGaN/GaN on Si	0.25	1.25	−8.49
IEMN	AlN/GaN on Si	0.16	1.0 (1.8)	−1.67
This work	InAlN/GaN on Si	0.17	1.16 (1.76)	1.36