High-frequency InAlN barrier transistors on silicon

Researchers claim record 16GHz-μm cut-off-gate-length product for gallium nitride channel HEMTs.

University of Delaware in the USA claims a record for radio frequency (RF) performance of indium aluminium nitride (InAlN)-barrier gallium nitride (GaN) high-electron-mobility transistors (HEMTs) on silicon [Peng Cui et al, Appl. Phys. Express, vol12, p104001, 2019]. The device also demonstrates records for direct current (DC) characteristics such as low gate leakage, high on/off current ratio, and subthreshold swing, according to the researchers.

Usually for high performance, GaN HEMTs are produced on very expensive silicon carbide (SiC) substrates. Growth on low-cost, large-diameter silicon should open up more economic opportunities for high-power and high-frequency GaN-based devices.

Metal-organic chemical vapor deposition (MOCVD) on (111) resulted in an epitaxial structure with a 2μm undoped GaN buffer, a 4nm $In_{0.12}Ga_{0.88}N$ back-barrier, a 15nm GaN channel, a 1nm AlN interlayer, an 8nm lattice-matched $In_{0.17}Al_{0.83}N$ barrier, and a 2nm GaN cap. Hall measurements gave sheet electron concentration and electron mobility values in the two-dimensional electron gas (2DEG) channel of $2.28 \times 10^{13}/cm^2$ and $1205cm^2/V$-s, respectively.

Device fabrication included plasma reactive-ion etch of isolation mesas, and alloying of titanium/aluminium/nickel/gold ohmic source-drain contacts at 850°C. The source–drain distance was 2μm. The researchers used an oxygen plasma treatment to oxidize the surface between the source and drain with the aim of reducing gate leakage current (I_g) and improve RF performance. The 80nm-long nickel/gold gate was centered in the source-drain gap.

The oxygen plasma treatment increased the on/off current ratio (I_{on}/I_{off}) by a factor of around two to reach 1.58×10^6. Another benefit was a reduction in subthreshold swing (SS) from 76mV/decade to 65mV/decade.

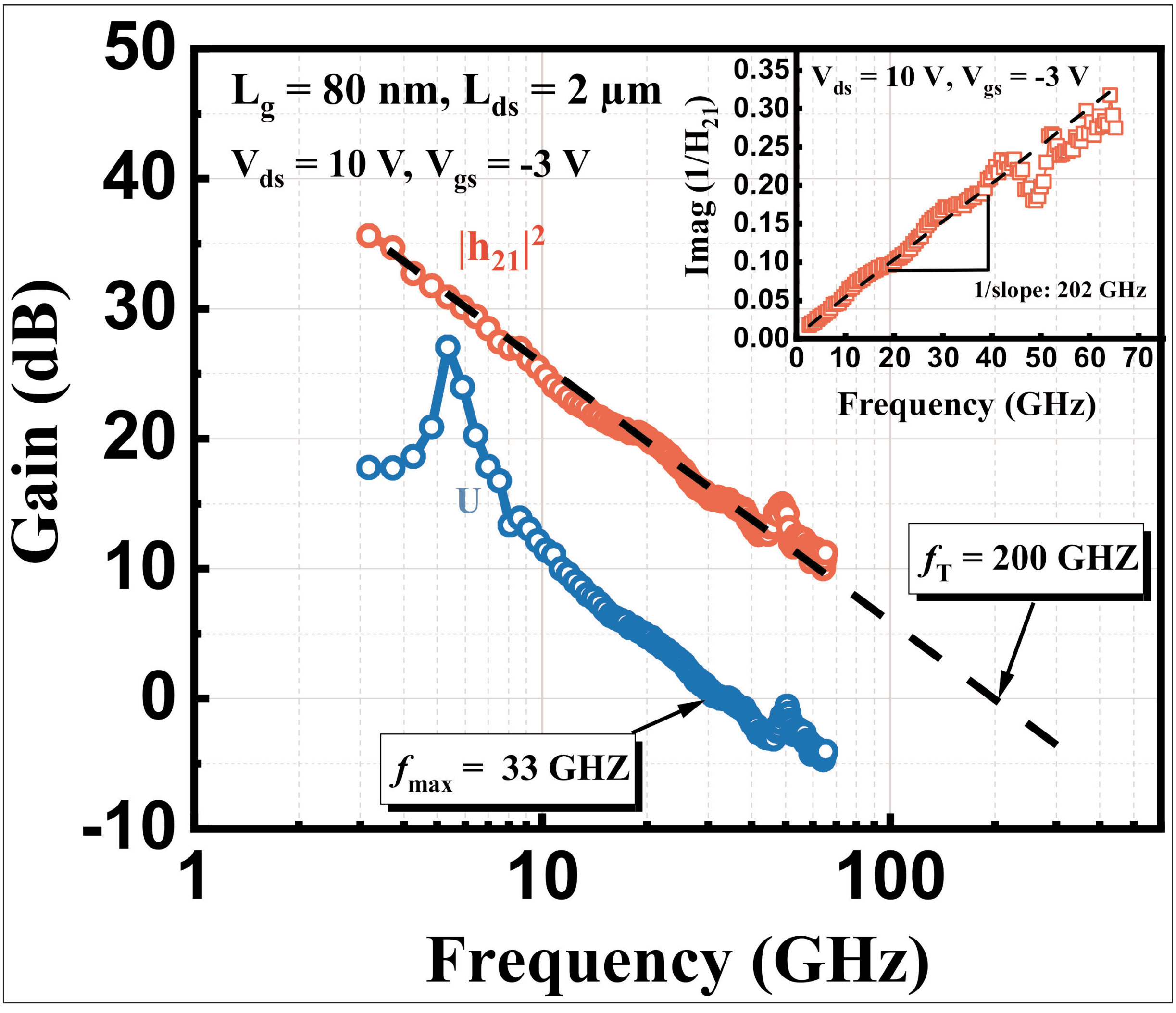

Figure 1. RF performance of 80nm-gate-length InAlN/GaN HEMTs with 200/33GHz f_T/f_{max}. Inset: Gummel's method showing 202GHz f_T estimate.

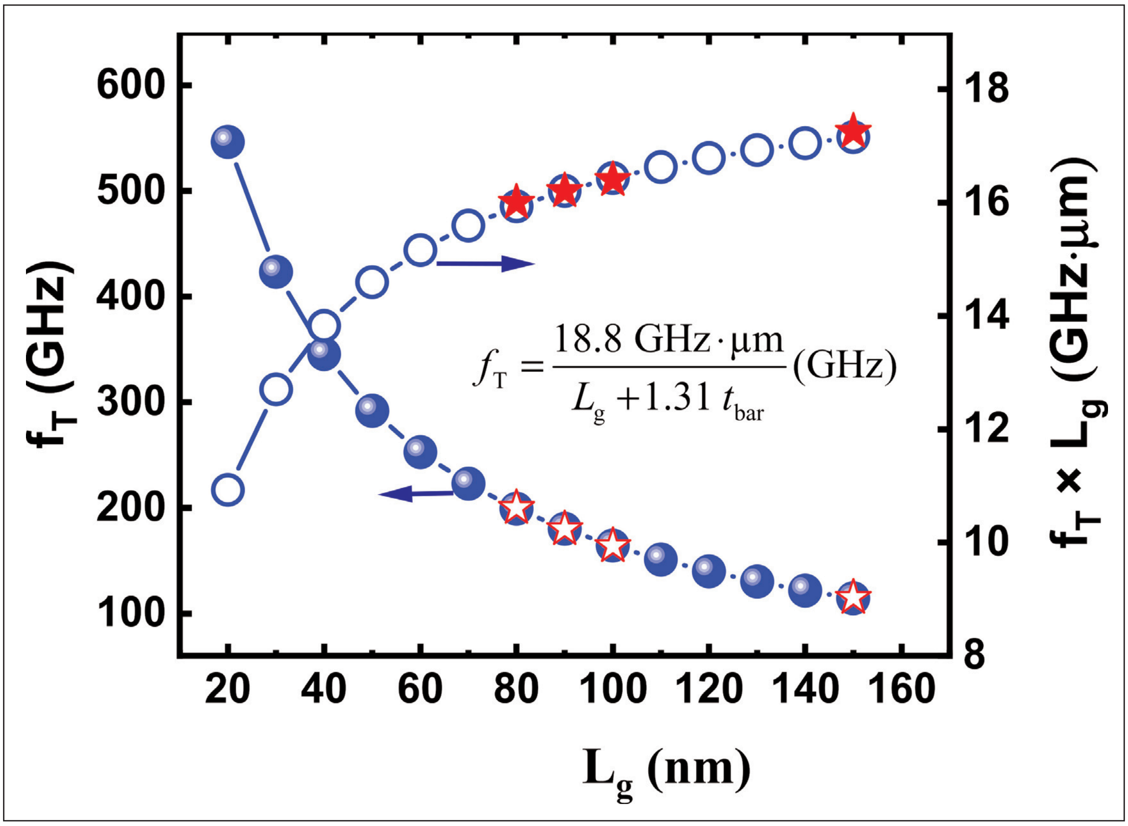

Figure 2. Predicted f_T (left) and f_TxL_g (right) as a function of L_g — stars represent experimental results.

The team comments: "To the best of our knowledge, the f_TxL_g in our study achieves the highest value among all reported GaN HEMTs on silicon, and set a new record among GaN HEMTs on SiC/Si with L_g <<100nm."

Using an empirical model that relates f_T to L_g, barrier thickness, the effective electron velocity and one fitting parameter, the researchers project that an f_T of 546GHz could be achieved with 20nm L_g, giving a f_TxL_g value of 10.9GHz-µm

The team comments: "To the best of our knowledge, these DC measurement results all show record values among those reported InAlN/GaN HEMTs on silicon to-date (I_g of 7x10^{-6}A/mm, I_{off} of 7x10^{-6}A/mm, I_{on}/I_{off} ratio of 1.78x10_5, and SS of 82mV/decade are the best values that have been reported in InAlN/GaN HEMTs)."

The researchers admit that better values have been obtained for I_g and I_{off} with 20nm aluminium gallium nitride (AlGaN) barrier HEMTs on silicon — of order 10^{-12}A/mm for both. The resulting I_{on}/I_{off} was 2.5x10^{11}.

However, one benefit of the thinner InAlN-based barrier was better electrostatic control of current flow in the channel, reducing short-channel effects (SCEs). The InGaN back barrier reduces losses from current leaking into the buffer layer and improves confinement of charge carriers to the GaN-channel region.

The peak transconductance of the InAlN-HEMT was 391mS/mm with 10V drain bias, beating a 75nm-gate 11.4nm-barrrier AlGaN-HEMT's 374mS/mm that has been reported. An 80nm-gate AlN-HEMT on silicon has been presented with 580mS/mm peak transconductance, enabled by a very thin 6nm barrier.

The 1.26A/mm maximum drain current of the team's InAlN-HEMT has also been bettered by a similar device on silicon with a very small 300nm source-drain gap (2.66A/mm). The wider 2µm gap of the team's HEMT naturally increased the on-resistance. One would expect, although the paper does not report on this, that the wider gap would lead to a higher breakdown voltage performance.

RF measurements were made in the 1–65GHz range (Figure 1). With parasitic elements accounted for ('de-embedded'), the current gain cut-off (f_T) was extracted as 200GHz, using a –20dB/decade extrapolation. The drain bias was 10V and the gate potential was set at –3V. The maximum oscillation/power gain (f_{max}) was 33GHz, suffering due to losses from the high resistance of the rectangular gate.

The cut-off-gate-length product (f_TxL_g) was 16GHz-µm. The researchers compare this with best result obtained on SiC — 17.8GHz-µm from 162GHz f_T and 110nm L_g. The team comments: "To the best of our knowledge, the f_TxL_g in our study achieves the highest value among all reported GaN HEMTs on silicon, and set a new record among GaN HEMTs on SiC/Si with L_g <<100nm."

Using an empirical model that relates f_T to L_g, barrier thickness, the effective electron velocity and one fitting parameter, the researchers project that an f_T of 546GHz could be achieved with 20nm L_g, giving a f_TxL_g value of 10.9GHz-µm (Figure 2). ■

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