Record 370GHz cut-off for InAlN barrier on GaN HEMT

Dielectric-free passivation, rectangular gates and re-grown contacts are shown to reduce the effects of parasitic resistance and capacitance.

University of Notre Dame (UND) and IQE RF LLC of Somerset, NJ, USA have achieved record cut-off frequencies of 370GHz for InAlN/AlN/GaN/SiC high-electron-mobility transistors (HEMTs) [Yuanzheng Yue et al, IEEE Electron Device Letters, published online 7 June 2012].

The use of indium aluminum nitride (InAlN) barrier layers rather than aluminum gallium nitride (AlGaN) allows lattice matching with GaN. In addition, a higher polarization discontinuity leads to higher charge density in the two-dimensional electron gas (2DEG) that forms in the GaN channel layer near the barrier/channel interface. The greater charge density allows for thinner barriers to be used, bringing the gate closer to the channel, improving electrostatic control.

In addition to use of the InAlN-based barrier layers, the UND/IQE team used dielectric-free passivation (DFP), rectangular gates and re-grown source–drain regions to improve performance through a reduction in the effects of parasitic passive resistance and capacitance.

The epitaxial structures were grown on silicon carbide using metal-organic chemical vapor deposition (MOCVD) — see Figure 1. The 1.6μm GaN buffer layer was iron-doped (Fe) to increase its resistivity, hence reducing the amount of current leakage through the buffer. A 200nm unintentionally doped GaN layer was followed by an AlN spacer and $In_{0.17}Ga_{0.83}N$ barrier that is lattice matched to GaN.

Silicon dioxide was used as a mask layer for etch and molecular beam epitaxy (MBE) of the source–drain regions. The separation between the 40nm-deep source–drain wells was 865nm. The source–drain material consisted of silicon-doped n-GaN, grown to a height of 80nm. Polycrystalline GaN was removed from the oxide with a buffer hydrofluoric acid lift-off process.

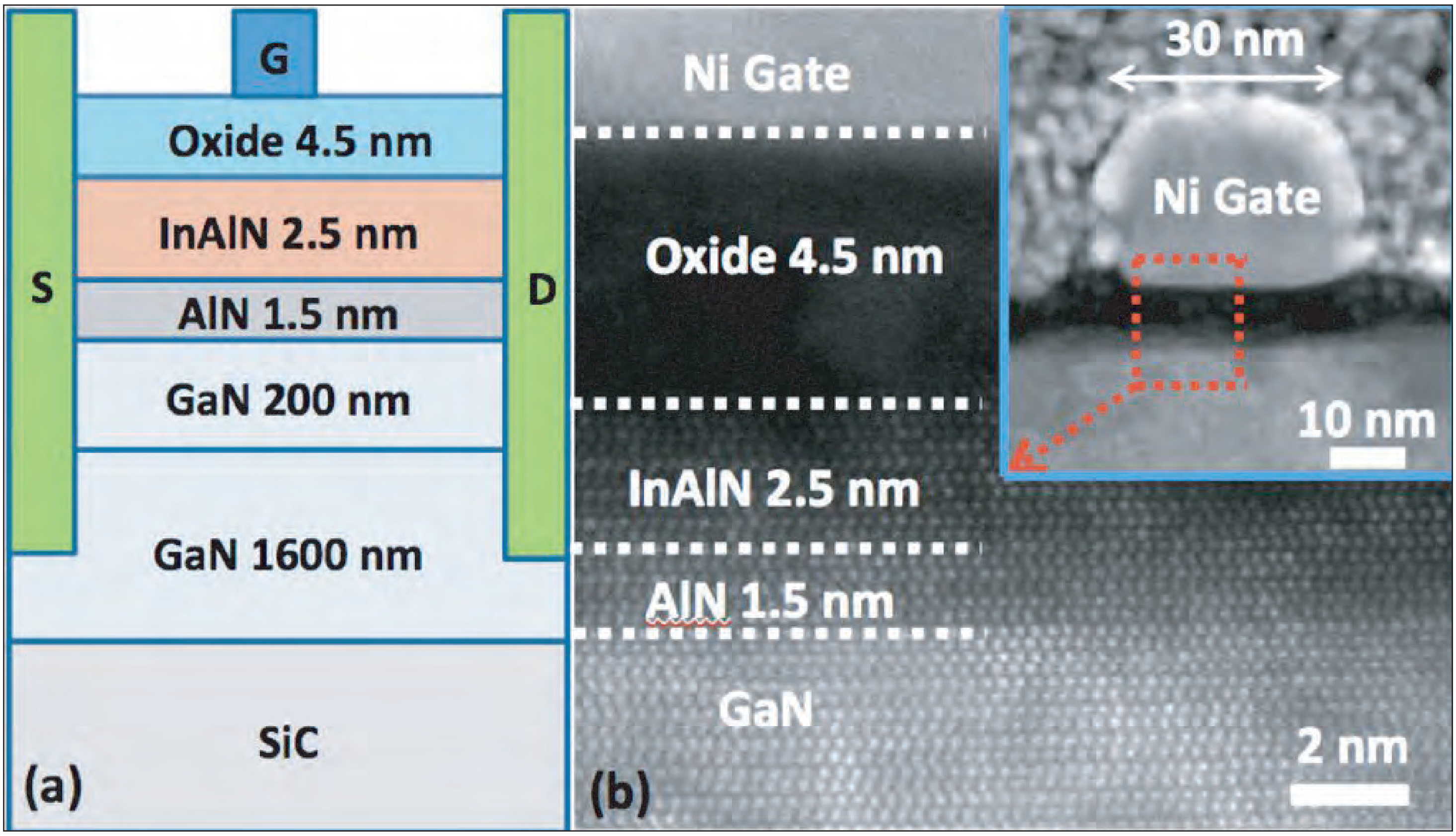

Figure 1. (a) Schematic of the InAlN/AlN/GaN HEMT cross section and (b) high-resolution TEM and (inset) scanning TEM images confirming HEMT layer structures and 30nm gate length after device fabrication.

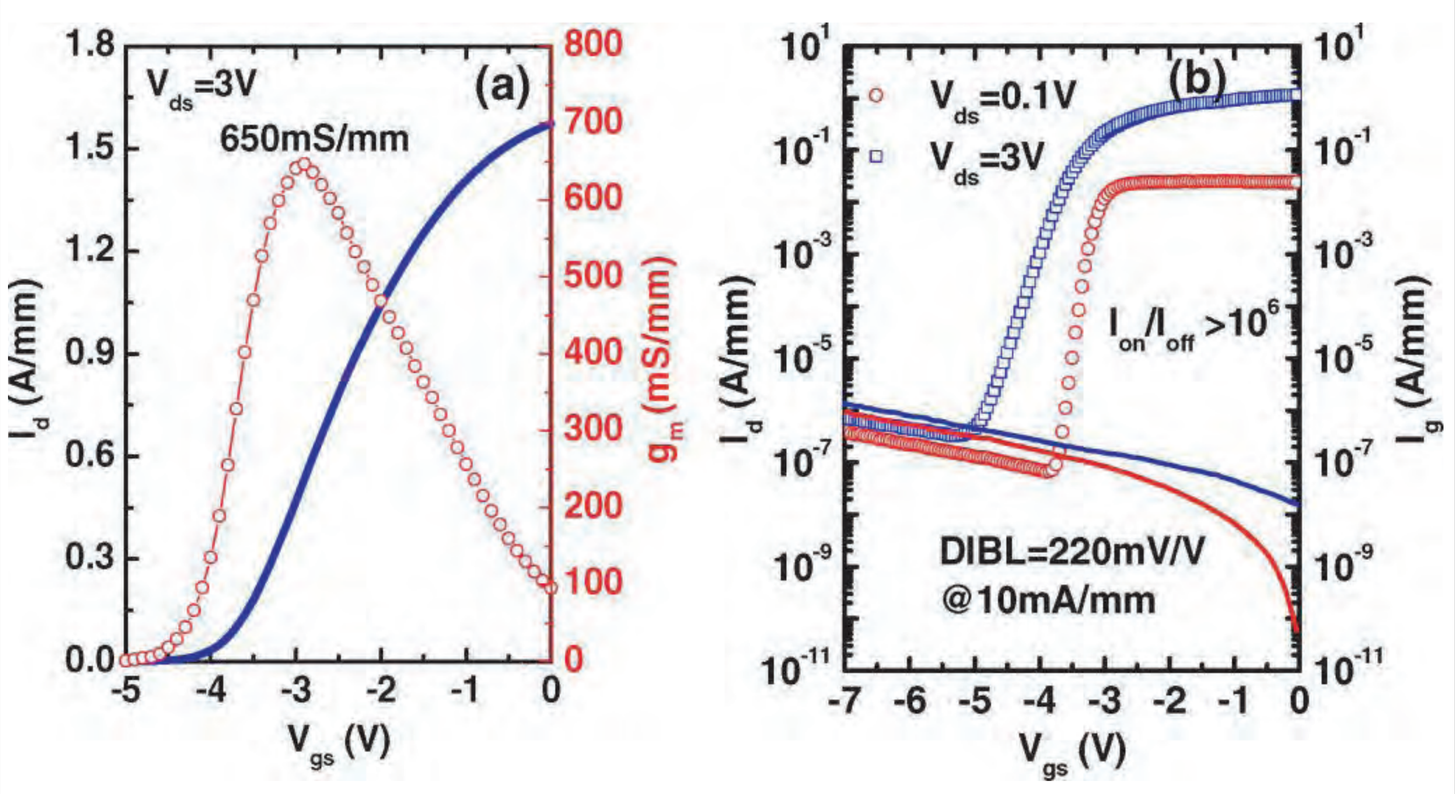

Figure 2. Transfer characteristics of InAlN/AlN/GaN HEMT at 3V and 0.1V drain biases: (a) linear scale and (b) semilog scale.

Ohmic source–drain contacts were made to non-alloyed titanium/aluminum layers. This was followed by mesa isolation using a chlorine plasma etch.

The dielectric-free passivation consisted of oxygen plasma treatment that oxidizes about 4.5nm of the original ~7.5nm InAlN barrier. Rectangular nickel gates were applied with a length of 30nm and a width of 2x25μm.

The maximum drain current of the resulting device was 1.5A/mm at zero gate potential and 5V drain. The on-resistance was 0.78Ω-mm between drain biases of 0 and 0.5V. The researchers find a difference 0.24Ω-mm, with the sum of the source and drain resistances (0.54Ω-mm) calculated on the basis of four-probe transmission line model (TLM) measurements. The origin of the difference is said to be unclear.

Pulsed measurements showed a slightly higher drain current at zero gate potential due to the suppression of self-heating. Nitride HEMTs often suffer 'current collapse' under such pulsed conditions. Although the device does not show current collapse, there is a 6% drain lag, "which merits further investigation".

The peak intrinsic transconductance was 650mS/mm at drain bias 3V and drain current 535mA/mm (Figure 2). The threshold was –3.5V. A high drain-induced barrier lowering (DIBL) of 220mV/V for 10mA/mm drain current is "indicative of significant short-channel effects" (SCEs).

On the plus side, the on–off ratio is more than six orders of magnitude (i.e. a factor of a million). The researchers also attribute the good pinch-off to "low gate leakage resulting from the blanket DFP treatment". The three-terminal breakdown for 1mA/mm at –12V gate potential was 30V..

The frequency performance was measured between 250MHz and 110GHz, giving a current gain cut-off (f_T) of 370GHz after correcting for the effects of parasitics (de-embedding). The uncorrected f_T was 160GHz. The researchers comment: "To the best of our knowledge, an f_T of 370 is the highest reported in any GaN-based HEMT".

Unfortunately, the maximum oscillation (f_{MAX}) was low, at 30GHz (27GHz pre-de-embedded) "due to the high gate resistance induced by the rectangular gate".

Based on analysis of various delay effects, the researchers believe that 500GHz f_T should be possible with shorter gates. To improve the f_{MAX} value, more work is needed on reducing parasitic effects and improving the transconductance through better electrostatic control of the channel. One way to do the latter may be to use AlN/GaN/AlN quantum well structures.

The work was supported by grants from the US Defense Advanced Research Projects Agency (DARPA) and the US Air Force Office of Scientific Research. ■

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