Record power-density AlGaN barrier transistors

Researchers use freestanding gallium nitride substrates to achieve output power density of 2W/mm at 40GHz.

Researchers in France claim record power performance at 40GHz from aluminium gallium nitride (AlGaN)-barrier high-electron-mobility transistors (HEMTs) on freestanding gallium nitride substrates [Mohamed-Reda Irekti et al, Semicond. Sci. Technol., vol34, p12LT01, 2019]. The output power density reached 2W/mm with 20.5% power-added efficiency.

Although higher power densities have been achieved at lower frequency, the device from University of Lille, Laboratoire d'Analyse et d'Architecture des Systèmes, and Université Côte d'Azur, beat a previous high at 40GHz of 1W/mm.

The researchers used 2inch-diameter freestanding GaN substrates commercially produced by Saint-Gobain Lumilog via hydride vapor phase epitaxy (HVPE). The substrate had a resistivity of less than 30mΩ-cm.

Metal-organic chemical vapor deposition (MOCVD) by the researchers added epitaxial layers of 10μm resistive GaN buffer, 1.5nm AlN, 11nm $Al_{0.26}Ga_{0.74}N$ barrier and 3nm in-situ silicon nitride cap (Figure 1). The resistive buffer was grown in two steps: 3μm carbon-doped

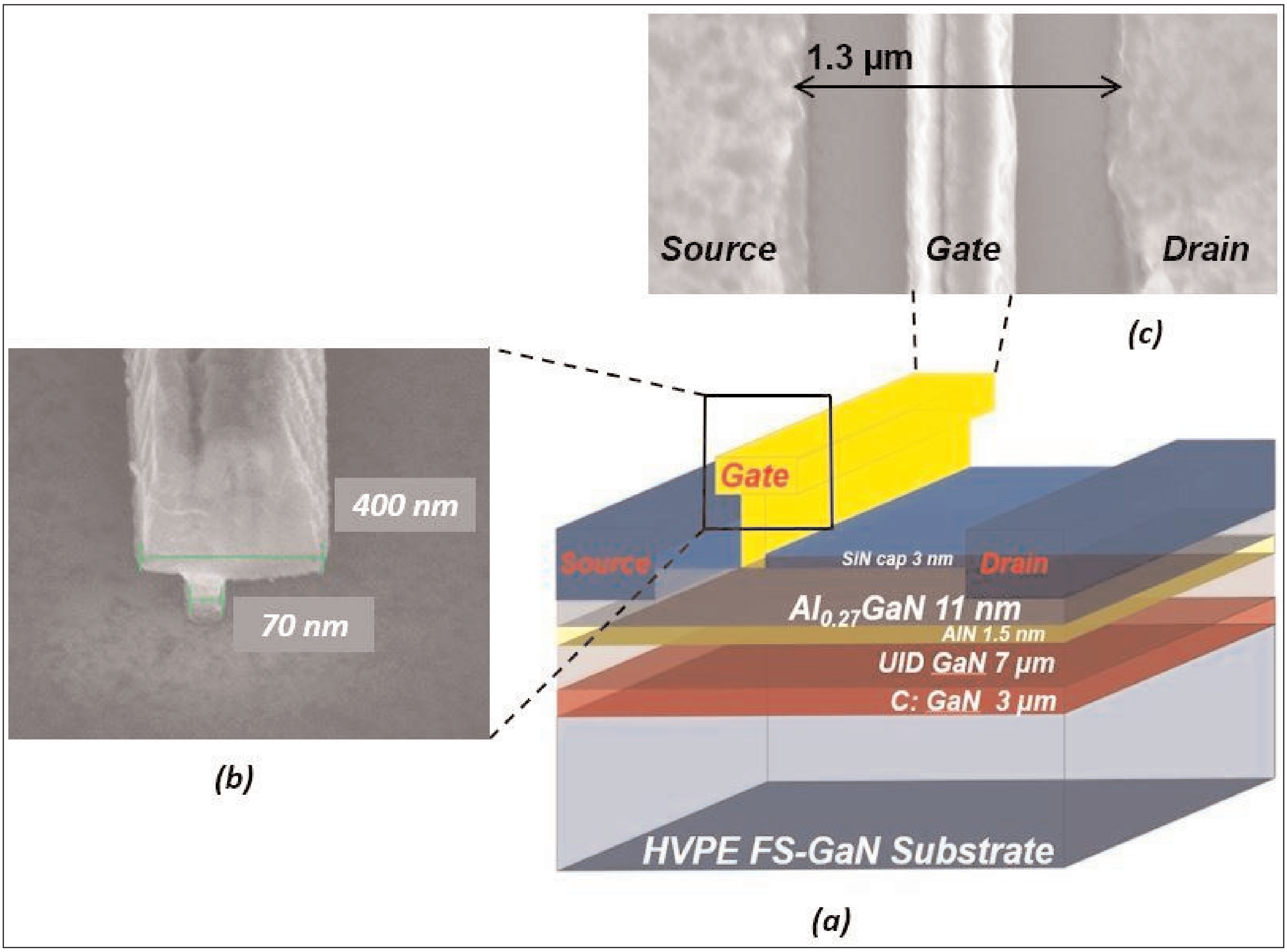

Figure 1. (a) Schematic of as-fabricated AlGaN/GaN HEMT on freestanding GaN substrate before passivation. Scanning electron micrographs: (b) after gate lift-off and (c) top view after gate fabrication.

GaN (C:GaN) and 7µm unintentionally doped GaN.

The exclusion layer aimed to reduce alloy scattering and enhance confinement of the electron carriers in the two-dimensional electron gas (2DEG) that formed the channel in the undoped GaN buffer near the interface. Hall-effect measurements gave $8.5 \times 10^{12}/cm^2$ electron density and $2200cm^2/V$-s. The corresponding sheet resistance was 356Ω/square.

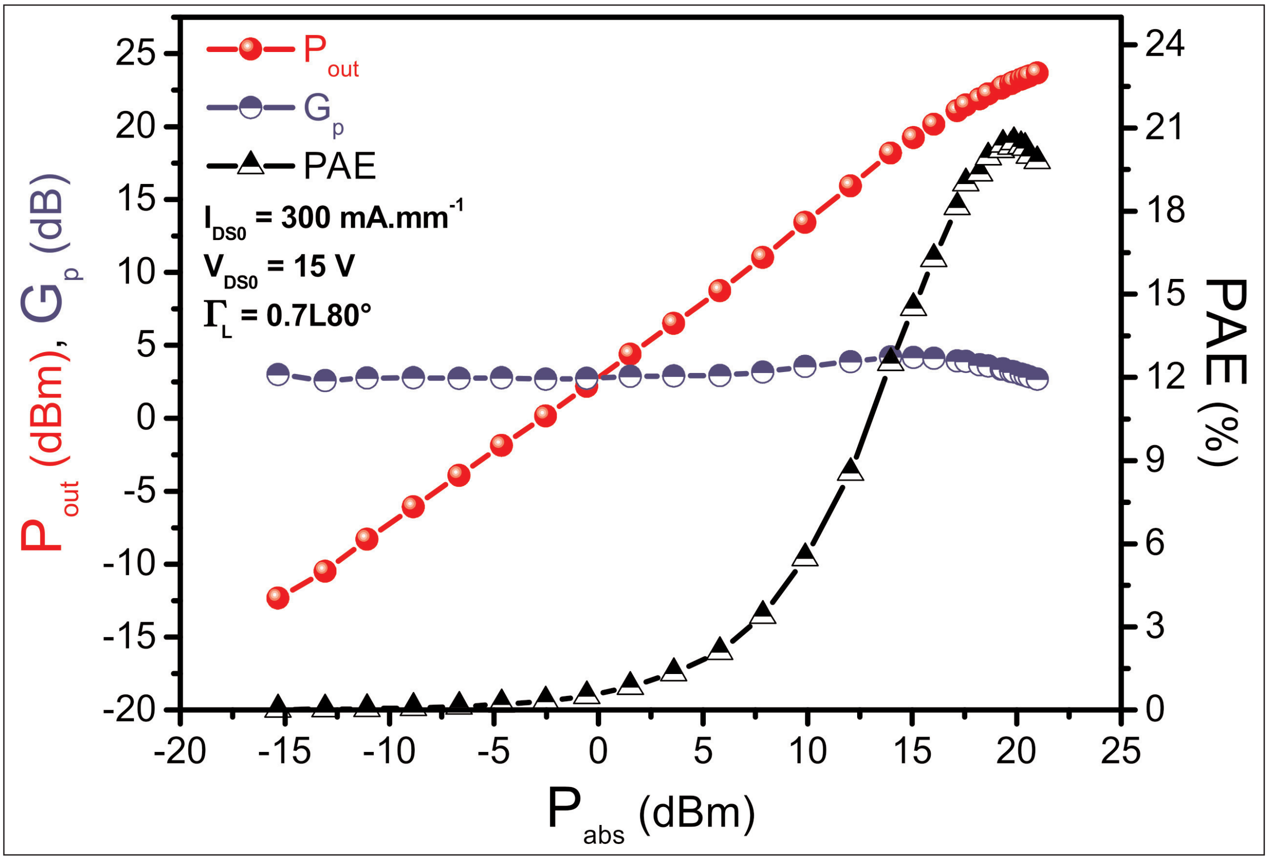

Figure 2. Output power, power gain and power-added efficiency vs absorbed power at 40GHz.

The use of freestanding GaN substrates avoids the need for nucleation layers, which simultaneously create thermal barriers. Nucleation layers are needed when growing III–nitrides such as GaN on silicon carbide or silicon. These layers are highly dislocated to allow growth of lattice and thermal expansion mismatched materials.

The source–drain regions of the HEMTs were fabricated by argon-ion-beam etching more than half way through the AlGaN barrier layer and electron-beam evaporating and annealing titanium/aluminium/nickel/gold metal contact stacks. The etching brought the contact metals closer to the 2DEG channel, reducing access resistance.

The devices were electrically isolated using nitrogen-ion implantation. T-shaped nickel/gold gates were formed with a 70nm foot on AlGaN barrier. A 20-minute 400°C anneal was carried out in nitrogen to improve the Schottky contact, reducing trap states.

The devices were passivated with 340°C plasma-enhanced chemical vapor deposition (PECVD) of silicon nitride. Metal connections with the device contacts were made with titanium/gold evaporation and patterning.

The tested devices consisted of two 50µm-wide gate fingers in a 1.3µm source-drain gap. The source–gate distance was 500nm.

With the gate at 1V relative to the source, the maximum drain current was 950mA/mm, and the on-resistance was 3Ω-mm. The transconductance under 6V drain bias peaked at 300mS/mm, when the gate was at −2.5V. The threshold was -3.5V. The gate leakage was as low at 3×10^{-7}A/mm, giving an on/off drain current ratio of more than 10^6.

Radio-frequency testing between 250MHz and 67GHz gave de-embedded/intrinsic gain cut-off frequency (f_T) and maximum oscillation (fmax) values of 100GHz and 125GHz, respectively. The researchers believe that these parameters can be increased with optimization of the C:GaN layer, improving the trade-off between crystal quality and buffer isolation.

Power performance was assessed at 40GHz with active load-pull measurements under continuous-wave operation (Figure 2). The drain bias was 10V with the current at 300mA/mm, giving AB-class operation. The output power density was 1.2W/mm with 26.2% power-added efficiency. Increasing the drain bias to 15V, but keeping the current flow the same, increased the power density to a 2W/mm record, while decreasing the efficiency to 20.5%. The linear gain was 5dB with 10V drain, and 4.2dB at 15V.

The researchers comment: "Up to now, this result constitutes the state-of-the-art large signal at 40GHz for AlGaN/GaN HEMTs on freestanding GaN substrate." ■

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