University of Glasgow and University of Cambridge in the UK have claimed the highest frequency performance to date for gallium nitride (GaN) high-electron-mobility transistors (HEMTs) on low-resistivity (LR) silicon (Si) [A. Eblabla et al, IEEE Electron Device Letters, published 23 July 2015]. The researchers see the technology as making viable cost-effective X-band and higher-frequency applications. The team also sees potential for such GaN devices in mobile communications where power management and radio frequency functions could be integrated on silicon. Normally, high-resistivity (HR) substrates are preferred for high-frequency devices to avoid losses from coupling with RF signals. However, even high-resistance silicon is costly.

The devices (Figure 1) were grown on 150mm silicon with resistivity less than $10 \times 10^2 \, \text{Ω}\cdot\text{cm}$, using metal-organic chemical vapor deposition (MOCVD). The 850nm iron-doped aluminium gallium nitride (AlGaN) buffer was graded to accommodate lattice and thermal expansion mismatch between GaN and Si. The 1.4µm GaN buffer was also iron-doped, yielding an insulating character. The researchers report: “The wafer was completely crack free with wafer bow after cooling from the growth temperature (1050°C) of 22µm (concave). This demonstrates that the lattice and thermal mismatch strains are well managed in the buffer layers and the wafer bow is compatible with processing through a commercial silicon fab.” Hall measurements on the two-dimensional electron gas (2DEG) in the GaN channel region gave $8.1 \times 10^{12} / \text{cm}^2$ carrier density, $1700 \, \text{cm}^2 / \text{V-s}$ mobility and $412 \, \Omega / \text{square}$ sheet resistance.

The transistor was fabricated using electron-beam lithography. The ohmic source-drain contacts consisted of titanium/aluminium/molybdenum/gold alloy. Following mesa isolation, silicon nitride was deposited as passivation and then nickel-chromium/gold for the T-gate. The maximum saturation current was 1.4A/mm at 10V drain and +1V gate for a device with 0.3µm gate length and 2x1.1µm width. The pinch-off at −4V is described as ‘well-behaved’. The on-resistance was 2.76Ω-mm. The maximum transconductance of 425mS/mm was achieved at 5V drain and −3.2V gate bias. The leakage current was 18.5nA/mm for 10V drain and −3.5V gate.

The researchers comment: “The excellent performance of these GaN-on-LR Si devices is the result of a well-engineered material growth, device layout and fabrication process quality in addition to proper passivation techniques. Moreover, these excellent results are competitive with other reported GaN HEMTs on high-resistivity substrates including sapphire and HR Si substrates.”

For frequency measurements, the small-signal gain was maximized by the bias point of 5V drain and −3.2V gate. The maximum current gain frequency ($f_T$) was 55GHz and the maximum oscillation frequency ($f_{max}$) was 121GHz, correcting (‘de-embedding’) for parasitic pad capacitances and inductances.

“’To our knowledge these are the best RF performance of GaN-based HEMTs on LR Si to date,’” the researchers write. Their RF results exceed in certain respects reports of devices on sapphire and high-resistivity silicon. For example, the $f_T$ of GaN HEMTs on high-resistivity silicon have reached 54GHz, while $f_{max}$ was 184GHz. Improved performance could be achieved with shorter gate lengths, thinner Al$_{0.25}$Ga$_{0.75}$N top-barrier, thicker GaN buffer and lower-resistance ohmic contacts. ■

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