High-performance GaN on low-resistance silicon

Highest frequency performance for transistors on low-resistance silicon substrate.

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 10Ω-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 $8.1 \times 10^{12}/cm^2$ carrier density, $1700 cm^2/V\text{-}s$ mobility and 412Ω/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 2x100μm 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."

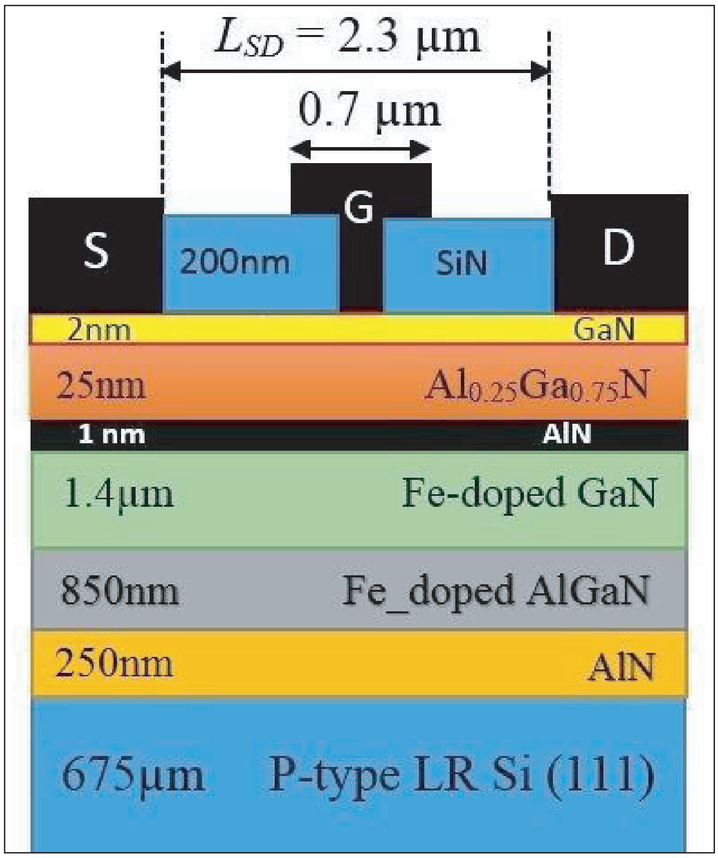

Figure 1. Fabricated T-gate AlGaN/AlN/GaN epilayer grown on LR p-type Si (111) with Si_3N_4 passivation.

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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