Self-aligned AlGaN/GaN high electron mobility transistors

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Self-aligned T-gate AlGaN/GaN high electron mobility transistors (HEMTs) were fabricated on a sapphire substrate using a thin Ti/Al/Ti/Au ohmic layer. To suppress the gate leakage current, the ohmic contact annealing was performed in a furnace. The self-aligned HEMTs with 0.25 µm gate length and 100 µm width exhibit good pinch-off characteristics, a transconductance of 146 mS/mm, an extrinsic unity current gain cutoff frequency of 38 GHz and a maximum oscillation frequency of 130 GHz.

Introduction: AlGaN/GaN high electron mobility transistors (HEMTs) have demonstrated high current levels, high breakdown voltages and high-frequency power performance due to their unique material properties [1, 2]. A higher Al concentration leads to a higher density of two-dimensional electron charge. However, the higher concentration makes it more difficult to form good ohmic contacts, leading to higher ohmic contact resistances and higher access resistances. To minimise the source access resistance, it is important to reduce the distances between gate to source and drain as closely as possible. Self-aligned AlGaN/GaN HEMTs are very attractive because of the minimised source access resistance, hence the ultrawide bandwidth. However, the thick metal scheme and high processing temperature of ohmic contacts hinder the realisation of self-aligned devices. So far, little has been reported on self-aligned AlGaN/GaN field-effect transistors. Chen *et al.* demonstrated AlGaN/GaN modulation-doped field-effect transistors with regrown ohmic contacts [3]. In this Letter, we report self-aligned AlGaN/GaN HEMTs with thin ohmic contacts annealed at 400°C.

In the self-aligned process, the thin ohmic level follows the gate metallisation. Therefore, it is crucial that the ohmic annealing temperature should not exceed some critical point above which the Schottky gate characteristics is significantly degraded. Recently, it was demonstrated that the breakdown voltage of AlGaN/GaN HEMTs with Ni/Au gate could be significantly improved after a thermal stressing process, even at 750°C in a furnace [4], which makes the fabrication of self-aligned devices feasible. In this Letter, we report the fabrication and characterisation of self-aligned AlGaN/GaN HEMTs.

Device fabrication: Fig. 1 shows the cross-sectional view of the self-aligned T-gate AlGaN/GaN HEMT. The epilayer of the AlGaN/GaN HEMT structure was grown by metal-organic chemical vapour deposition (MOCVD) on (0001) sapphire substrate. The epilayer consists of 40 nm AlN nucleation layer, 3 µm of undoped GaN, and 20 nm undoped $Al_{0.3}Ga_{0.7}N$.

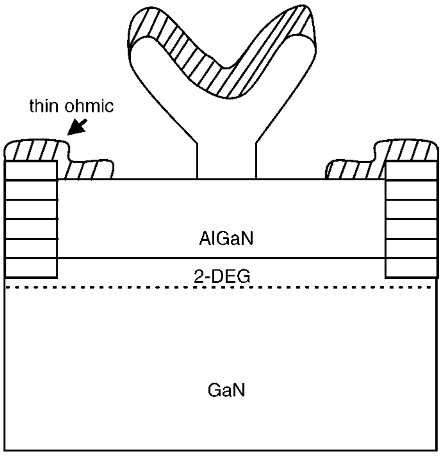

Fig. 1 *Cross-sectional view of self-aligned T-gate AlGaN/GaN HEMT*

For device fabrication, device isolation was obtained with shallow mesa dry etching in a chlorine-based plasma. The drain-source ohmic contacts with 3.5 µm spaces were deposited with Ti/Al/Pd/Au and annealed at 850°C for 30 s in a rapid thermal annealing system. This level was included to ensure the formation of the ohmic contact. Electron-beam lithography and Ni/Au metallisation were used for gate contacts with a gate length of 0.25 µm. The Ti/Al/Ti/Au thin ohmic layer with a thickness of 80 nm was deposited and annealed in a furnace at 750°C for 30 min in N_2 ambient. The ohmic layer was self-aligned to the T-gate using gate overhangs as a shadow mask. The annealing processing condition is chosen to ensure the formation of ohmic contact and the suppression of gate leakage current. The contact resistivity and contact resistance of the thin ohmic layer were determined typically to be $6.5 \times 10^{-6}\ \Omega\,cm^{-2}$ and 0.95 Ω mm using transfer length measurement patterns. An Ni/Au layer was deposited for overlay. Fig. 2 shows a SEM photograph of a typical 0.25 µm self-aligned AlGaN/GaN HEMT. It shows very smooth morphology of the thin ohmic layer even after annealing.

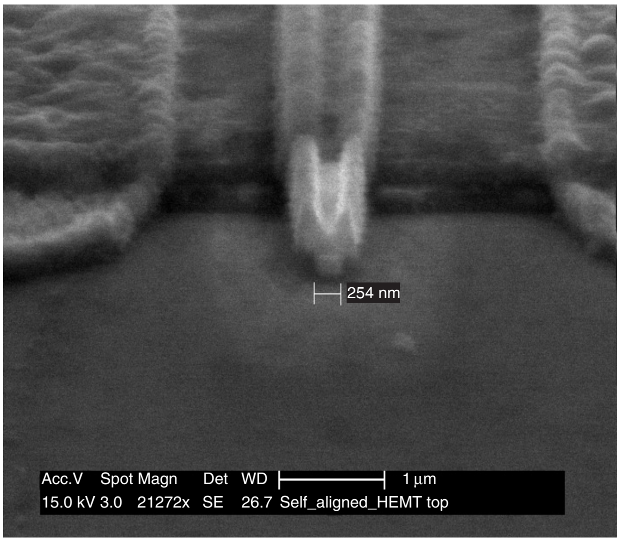

Fig. 2 *SEM photograph of self-aligned T-gate AlGaN/GaN HEMT*
Gate length = 0.25 µm

Results and discussion: Fig. 3 shows the typical drain current characteristics of self-aligned T-gate AlGaN/GaN HEMTs with 0.25 µm gate length and 100 µm gate width. Despite the small separation between gate and drain, the device exhibits excellent pinch-off behaviour. The gate bias ranges from −8 to 1 V with a step of 1 V. The maximum drain current is 620 mA/mm at a gate bias of 1 V and pinch-off voltage is −7 V. The knee voltage is 4 V. At gate biases of 1, 0, and −1 V, the current–voltage characteristics at drain bias voltage higher than 8 V exhibit negative differential resistance characteristic of self-heating due to poor thermal conductivity of the sapphire substrates [5]. A maximum extrinsic transconductance (g_m) of 146 mS/mm is obtained at a gate voltage of −3.4 V and at a drain bias voltage of 6 V. From the gate-bias intercept of the extrapolation of the drain current curve, a threshold voltage of −5.5 V is determined.

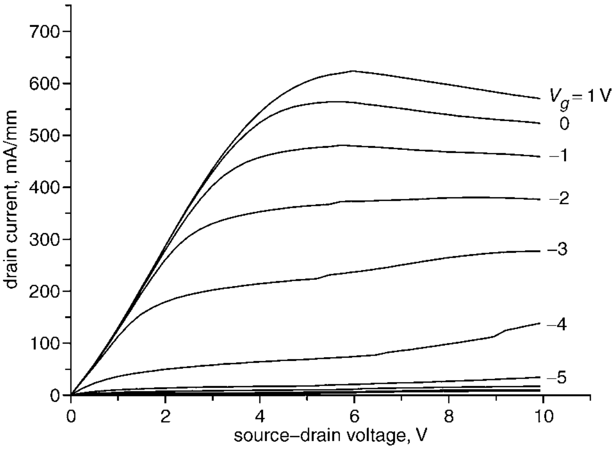

Fig. 3 *I–V characteristics of 0.25 µm self-aligned AlGaN/GaN HEMTs*
Gate bias ranges from −8 to 1 V with step of 1 V

For microwave characteristics, on-wafer measurements of small-signal S-parameters were performed from 1 to 50 GHz to determine f_T (cutoff frequency) and f_{MAX} (maximum oscillation frequency) of the self-aligned devices. Fig. 4 shows plots of current gain and maximum stable power gain (MSG) and maximum available gain (MAG) against frequency. f_T and f_{MAX} were determined by the extrapolation of $|h_{21}|$ and MSG/MAG with −20 dB/decade slope. The devices exhibited an f_T of 38.8 GHz and an f_{MAX} of 130 GHz at a gate bias of −3.5 V and a drain bias of 5 V.

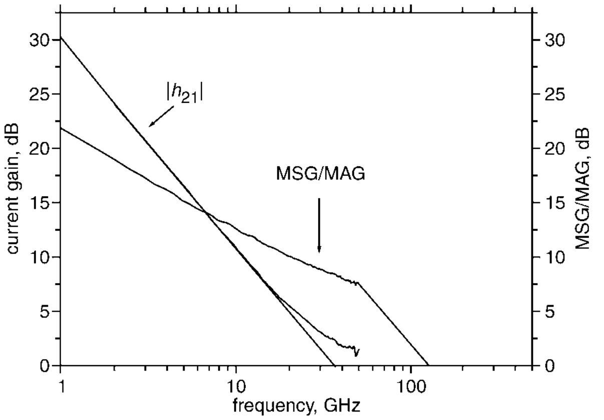

Fig. 4 *Current gain and maximum stable/available power gain of 0.25 µm self-aligned AlGaN/GaN HEMTs*

Conclusions: We have reported the fabrication and DC and small-signal characterisation of self-aligned T-gate AlGaN/GaN HEMTs with 0.25 µm gate length and 100 µm width on a sapphire substrate, which exhibit good pinch-off characteristics and the maximum oscillation frequency (f_{MAX}) of 130 GHz. It is believed that significant improvements on self-aligned AlGaN/GaN HEMT performances will be demonstrated in the near future by further optimisation of the thin ohmic process. To our knowledge, these devices are the first self-aligned AlGaN/GaN HEMTs fabricated without using a regrown process.

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