# Wide Head T-Shaped Gate Process for Low-Noise AlGaN/GaN HEMTs

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The low-noise performance of GaN-based HEMT devices provide both robustness and power-handling capability, which eliminate the need for additional protection circuits in front-end receiver applications [1-2]. To date, most of microwave noise studies on GaN-based HEMTs [2–5] have been reported for the conventional T-gated device having the reduced gate-length $L_g$ and source-drain spacing $L_{sd}$. To improve the noise performance of these devices, it is necessary to reduce the parasitic gate resistance $R_g$ as well as the scaling of $L_g$ and $L_{sd}$ [6]. However, little work has been reported on the microwave noise performance of GaN HEMTs with a wide head T-shaped gate to further reduce $R_g$. In this work, we present a wide head T-shaped gate process for low-noise AlGaN/GaN HEMTs, and demonstrate the low-noise microwave performance of 0.18 μm gate-length GaN HEMTs on SiC with a wide head T-shaped gate.

The AlGaN/GaN HEMT structure on 4-inch SiC substrate was used for developing a wide head T-shaped gate process and fabricating low-noise AlGaN/GaN HEMTs. The epitaxial layer stack consists of a nucleation layer, 2 μm of Fe-doped GaN buffer layer and a barrier layer of 25nm-thick $Al_{0.25}Ga_{0.75}N$. The device fabrication started with Ti/Al/Ni/Au ohmic metallization followed by rapid thermal annealing. Then, 50 nm thick SiN layer was deposited using plasma-enhanced chemical vapor deposition. The first metal-interconnections with ohmic contacts were formed by evaporation of Ti and Au metal after etching SiN layer. The wide head T-shaped gate process was developed using two-step e-beam lithography. A gate footprint of 0.18 μm was first formed by e-beam exposure in PMMA resist and SiN layer underneath the gate pattern was etched by reactive ion etching. Secondly, a wide head T-shaped gate pattern was directly written by another e-beam exposure after coating PMMA/Co-polymer/PMMA triple layers and the gate recess was performed using inductively coupled-plasma etching with $BCl_3/Cl_2$ gas. 30 nm Ni/500 nm Au gate metals were then evaporated and lifted off. Airbridge-pad interconnections were finally formed with Au-plating process in the devices. A SiN PECVD film was deposited for device passivation. The devices had $L_{sd}$ of 3.5 μm and total gate width of 150 μm (2 x 75 μm).

Fig. 1 shows the transmission electron microscope (TEM) image of the wide head T-shaped gate developed in this work. A wide head T-shaped gate electrode has the high ratio of a wide-head gate (1.07 μm) to a narrow gate footprint (0.18 μm). The gate structure shows that the overlapped-area between the gate and the dielectric layer is small, even besides large cross-sectional gate area, which results in lower gate parasitic capacitance and resistance.

Fig. 2 shows the current-voltage characteristics of a typical device with $L_g$ of 0.18 μm and $L_{sd}$ of 3.5 μm. The devices exhibited good pinch-off behavior with a drain saturation current density $I_{dss}$ of 630 mA/mm at $V_{gs}$ of 0 V. The gate leakage current was as small as 0.5 μA at $V_{gs}$ of 10 V on the devices. Fig. 3 shows the transfer characteristics of the device. The maximum transconductance $g_{max}$ of 270 mS/mm was measured at $V_{gs}$ of – 2.85 V and $V_{ds}$ of 10 V. Fig. 4 shows the measured current gain $h_{21}$ and maximum stable/available gain (MSG/MAG) versus frequency for the device. As shown in Fig. 4, The $f_T$ and $f_{max}$ for the devices are 45 and 137 GHz, respectively.

Microwave noise performance of the devices was measured between 4 and 18 GHz using Maury noise parameter test set and Agilent 8510C network analyzer. Fig.5 shows microwave noise characteristics as a function of frequency for the passivated devices with a wide head T-shaped gate. For these measurements, devices were biased at $V_{ds}$ = 5 V and $V_{gs}$ = –2.75 V. At the bias condition, the drain current density was 87 mA/mm, and the devices showed minimum noise figure $NF_{min}$ of 0.81 dB and associated gain $G_a$ of 12.1 dB at 10 GHz. At 18 GHz, $NF_{min}$ and $G_a$ were 1.41 dB and 9.6 dB, respectively. The noise data at 10 GHz is the best ever reported for GaN HEMTs with similar gate-length and geometry, which is attributed to the reduction of gate resistance resulting from the large cross-sectional area of the wide head T-gate. Further improvement of noise performance will be possible with the reduction of gate-length and the lateral scaling of the GaN HEMTs for low-noise microwave applications.

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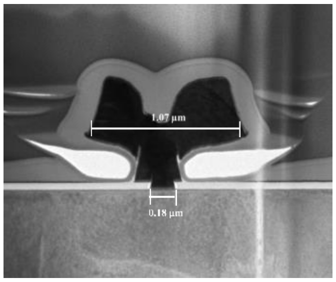


Fig. 1**.** Cross-sectional TEM image of wide head T-shaped gate electrode developed in this work. A wide head T-shaped gate has a narrow gate footprint (0.18 µm) and a wide head gate (1.07 µm).

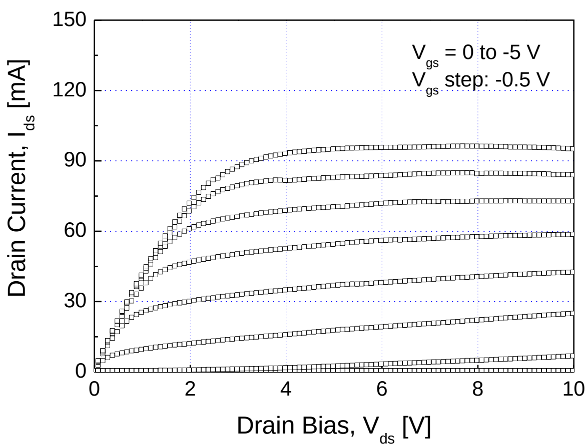


Fig. 2. Current-voltage (I-V) characteristics of the devices with $L_{sd}$ of 3.5 µm and $L_g$ of 0.18 µm. Total gate width is 150 µm (2 x 75 µm).

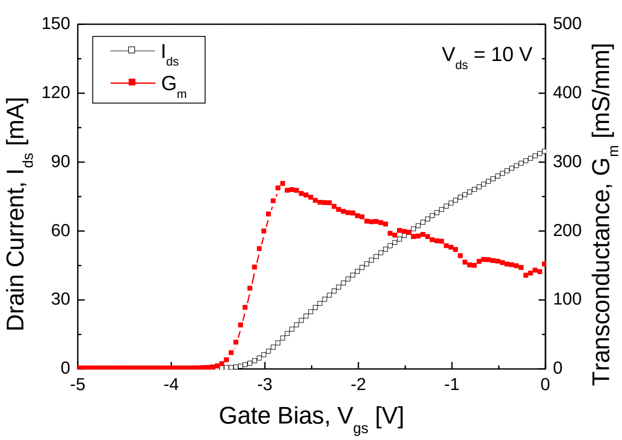


Fig. 3. Transfer characteristics at drain source $V_{ds}$ of 10 V for the devices with $L_{sd}$ of 3.5 µm and $L_g$ of 0.18 µm.
Total gate width is 150 µm (2 x 75 µm).

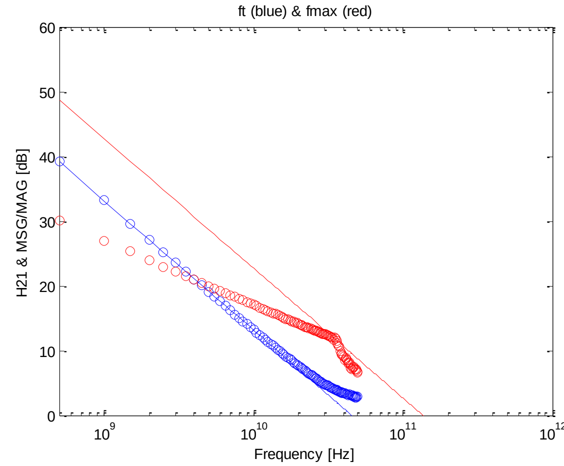


Fig. 4.Measured current gain gain $h_{21}$ and maximum stable/available gain (MSG/MAG) as a function of frequency for 0.18 µm gate-length AlGaN/GaN on SiC with wide head T-shaped gate Total gate width is 150 µm (2 x 75 µm). Device was biased at $V_{ds}$= 10 V and $V_{gs}$= – 2.7 V

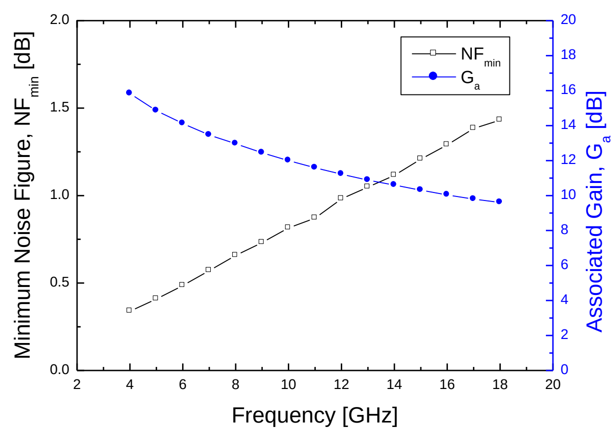


Fig. 5. Minimum noise Figure $NF_{min}$ and associated gain $G_a$ as a function frequency for 0.18 µm gate-length AlGaN/GaN on SiC with wide head T-shaped gate. Device was biased at $V_{ds}$= 5 V and $V_{gs}$= – 2.75 V.