

p-GaN/AlGaIn/GaN Enhancement-Mode HEMTs

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GaN-based enhancement-mode (E-mode) HEMTs are attracting significant interest for integration of control circuitry and for the added safety of a normally-off device in power switching applications. While previous work reports excellent performance by gate-recessing¹ and Fluorine-based plasma treatment², the Schottky gate turn-on voltage of these devices are at most 2 V. Because high-power switching applications require a threshold voltage of over 1 V for gate signal noise immunity, increasing the gate turn-on voltage is crucial. Utilization of p-GaN barrier below the gate³ depletes the channel and increases the gate turn-on voltage to 3 V, rendering it attractive for high-power applications. In this report we present a p-GaN/AlGaIn/GaN E-mode HEMTs with a 3 V gate turn-on and maximum output current exceeding 0.3 A/mm. In addition, pulsed I-V measurement and small-signal performance of these devices are presented and the design space of p-GaN gated E-mode HEMTs are investigated for high-power switching applications.

The devices used for this study were fabricated on material grown by RF plasma-assisted molecular beam epitaxy. The schematic cross section of the device is shown in Fig. 1. The Mg doping concentration in the 10 nm-thick p-GaN layer was approximately $1 \times 10^{18} \text{ cm}^{-3}$ and the thickness of the $\text{Al}_{0.22}\text{Ga}_{0.78}\text{N}$ layer was 12 nm. The p-GaN in the source/drain regions was etched away prior to ohmic metal deposition using a self-aligned dry etch while the p-GaN in the access regions was etched away using the ohmic contacts and the gate electrode as masks. Peak g_m of 160 mS/mm is reached at V_{GS} of 1.4 V and the threshold voltage is 0.5 V as shown in Fig. 2. The 3 V turn-on of the gate diode is approximately 1 V higher than standard Schottky gates as shown in Fig. 3.

The DC, 80 μs , and 200 ns-pulsed I-V output characteristics of the device are shown in Fig. 4. The maximum output current of the device is the highest reported among p-GaN gated E-mode HEMTs. The kink in the pulsed I-V, which may be caused by traps in the p-GaN/AlGaIn interface, is currently under investigation. Consequently, the device exhibits f_T of 12 GHz and f_{max} of 35 GHz which are lower than that of depletion-mode (D-mode) devices with similar dimensions. Similar behavior has been observed and solved in other GaN-based HEMTs that have GaN/AlGaIn interfaces with net a negative polarization charge⁴. Application of similar solutions is currently being evaluated as well.

In order to realize a p-GaN gated device with a threshold voltage of 1 V and high current density, calculations indicate the need for an AlN interlayer due to trade-off between threshold voltage and access resistance as shown in Fig. 5, and 6. Without an AlN interlayer, threshold voltage of 1 V can be achieved, but the device will exhibit extremely low current due to high access resistance. With an AlN interlayer, threshold voltage of 1 V can be achieved with much lower access resistance. Work is in progress to develop p-GaN/AlGaIn/AlN/GaN E-mode HEMTs with a threshold voltage of 1 V and high current density.

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³X. Hu et al. *Electronics Letters*, Vol. 36, p. 753 (2000)

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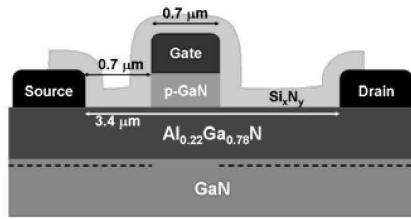


Fig. 1: Schematic cross section of the p-GaN/AlGaIn/GaN E-mode HEMT.

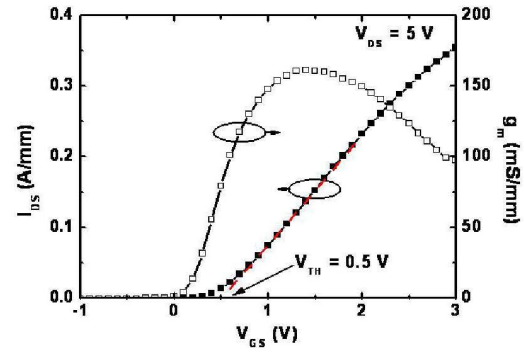


Fig. 2: The gate transfer characteristics. Peak $g_m=160$ mS/mm at $V_{GS}=1.4$ V and V_T is 0.5 V.

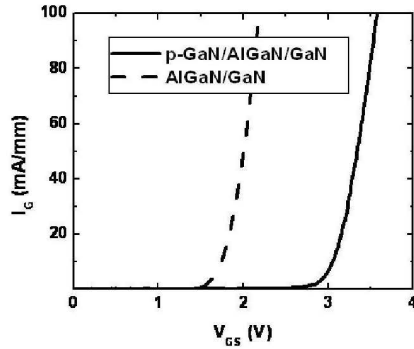


Fig. 3: I-V characteristics of gate diodes.

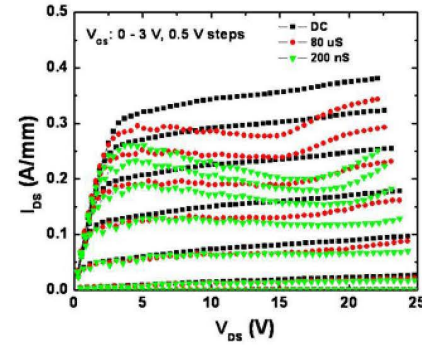


Fig. 4: The DC, 80 μ s, and 200 ns pulsed current-voltage output characteristics.

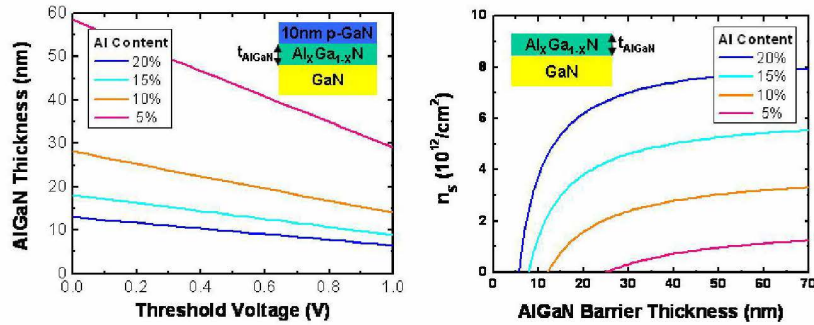


Fig. 5: AlGaIn thickness vs. threshold voltage, sheet charge vs. AlGaIn thickness for p-GaN/AlGaIn/GaN structure (calculation). Sheet charge density is very low at AlGaIn thickness required for threshold voltage of 1 V.

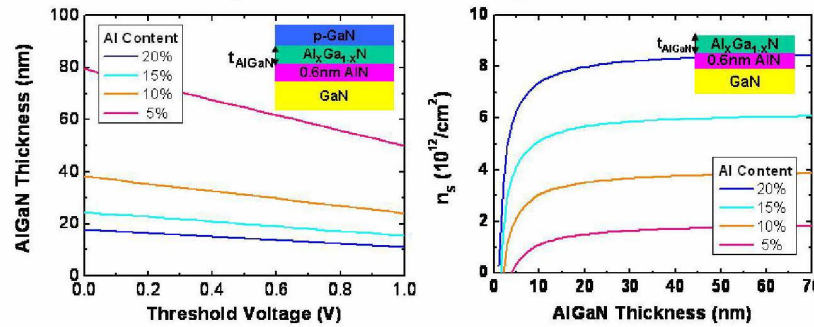


Fig. 6: AlGaIn thickness vs. threshold voltage, sheet charge vs. AlGaIn thickness for p-GaN/AlGaIn/AlN/GaN structure (calculation). Sheet charge density is high at AlGaIn thickness required for threshold voltage of 1 V.