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Enhancement-Mode AlGaN/GaN HEMTs with High Linearity Fabricated by Hydrogen Plasma Treatment

Bin Lu[1], **Omair I. Saadat**[1], **Edwin L. Piner**[2] **and Tomas Palacios**[1]

[1] *Department of Electrical Engineering and Computer Science, Massachusetts Institute of Technology, Cambridge, MA, 02139*

[2] *Nitronex Corporation, Durham, NC, 27703*

Email: binlu@mit.edu Phone: 617-253-0715

Enhancement-mode (E-mode) AlGaN/GaN high electron mobility transistors (HEMTs) are highly desirable for power and digital electronic circuits. Several technologies have been demonstrated in the last few years to fabricate E-mode devices. For example, gate recess can be applied to conventional AlGaN/GaN HEMTs to achieve E-mode operation [1]. However, these devices have very low threshold voltage and large gate leakage. Alternatively, the use of CF_4 plasma treatment in the gate region prior to gate metallization results in E-mode AlGaN/GaN HEMTs with higher threshold voltage [2].

In this paper, we demonstrate E-mode AlGaN/GaN HEMTs by hydrogen plasma treatment. The results are compared to the F-treated HEMTs and depletion-mode (D-mode) HEMTs and important differences have been found in the linearity of these transistors.

All the devices used in this work were fabricated on GaN/$Al_{0.26}Ga_{0.74}N$/GaN samples grown by metalorganic chemical vapor deposition on Si (111) substrates. These wafers have a 20 Å i-GaN cap layer and a 175 Å i-$Al_{0.26}Ga_{0.74}N$ barrier. Source and drain ohmic contacts were fabricated with a Ti/Al/Ni/Au metallization and alloyed for 30 s at 870 ^{o}C. Mesa isolation was formed by BCl_3 and Cl_2 plasma etching. After gate lithography, some devices were exposed to H_2 plasma in an ECR-RIE system with 100 W ECR power and 100 V DC bias for 200 s. A second set of devices was exposed to CF_4 plasma in the same ECR-RIE system with 100 W ECR power and 20 W RF power for 80 s corresponding to a DC bias of 370 V. Finally, a third set of devices which did not receive any gate treatment was used as a reference. Ni/Au/Ni was deposited by electron-beam evaporation to form the gate. The gate length of all the transistors is 2 μm. The gate-to-source and gate-to-drain distance is 2 μm.

The H_2 plasma treatment shifted the threshold voltage of the D-mode HEMTs from -1.6 V to +1.8 V, as shown in Figure 1. It has very low drain current of 3.6 μA/mm at V_{gs} = 0 V and V_{ds} = 5 V, which demonstrates the excellent E-mode behavior. The extrinsic transconductance (g_m) of the H-treated sample reaches 93 mS/mm in the measured voltage range. The I_{ds}-V_{ds} and I_g-V_{gs} characteristics are shown in Figure 2 and Figure 3. More than two orders of magnitude lower gate leakage is observed in the H-treated HEMT with respect to the D-mode devices. After a 30 min annealing at 175 ºC, the H-treated sample shows an increase in g_m and I_{ds} (Figure 4) and drain current was 1.7 μA/mm at V_{gs} = 0 V and V_{ds} = 5 V. No degradation was observed.

The behavior of the transconductance as a function of V_{gs} is very different in the three samples analyzed in this work. As shown in Figure 1, the transconductance of the H-treated E-mode devices increases more slowly as a function of V_{gs} than in the D-mode and CF_4-treated E-mode HEMTs. For a MOSFET-like device operating in the saturation region, the extrinsic transconductance can be expressed as $1/g_m = R_s + \sqrt{L_g/2\mu C_{ox}}/\sqrt{I_{ds,sat}}$, where R_s is the source access resistance; L_g is the gate length and C_{ox} is the gate capacitance per unit area. Figure 5 plots $1/g_m$ vs $1/\sqrt{I_{ds}}$. The H-treated E-mode HEMT shows much better linearity as described by the previous equation than the CF_4-treated E-mode HEMT and the D-mode HEMT.

In conclusion, we demonstrate a new method to fabricate AlGaN/GaN E-mode transistors by H_2 plasma treatment. The devices fabricated through this new technology compares favorably with D-mode and F-treated transistors and show much more ideal (i.e. linear) transfer characteristics.

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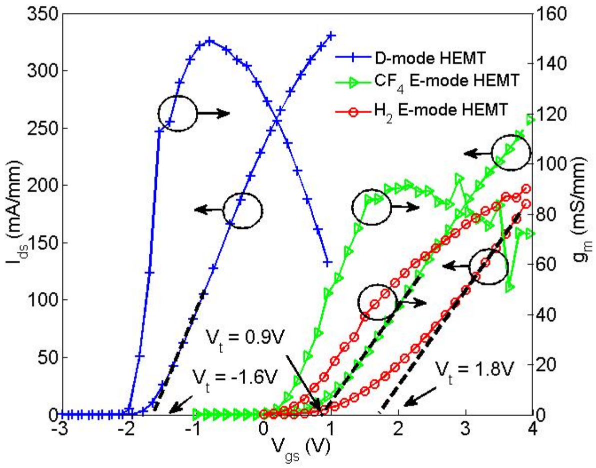

Fig. 1: Transfer characteristics at V_{ds}=5 V of D-mode and E-mode HEMTs treated by H_2 and CF_4 plasma.

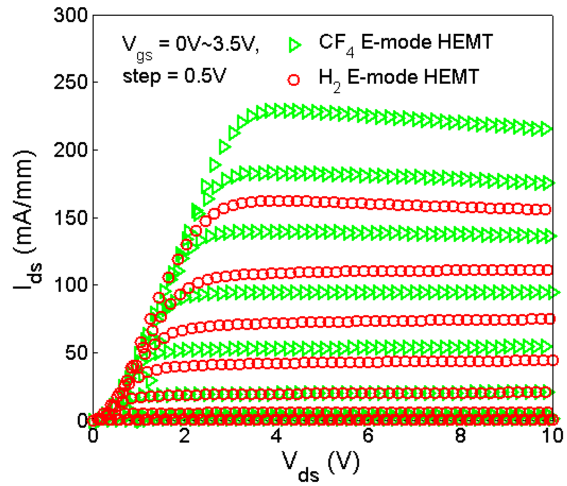

Fig. 2: I_{ds}-V_{ds} characteristics of E-mode HEMTs fabricated by CF_4 and H_2 plasma treatments.

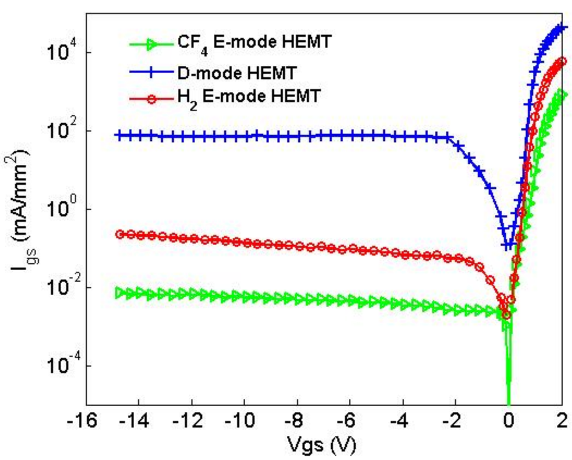

Fig. 3: I_{gs}-V_{gs} characteristics of three different samples studied in this paper. The H_2 treated E-mode HEMT shows more than 2 order of magnitude lower gate leakage than D-mode HEMTs.

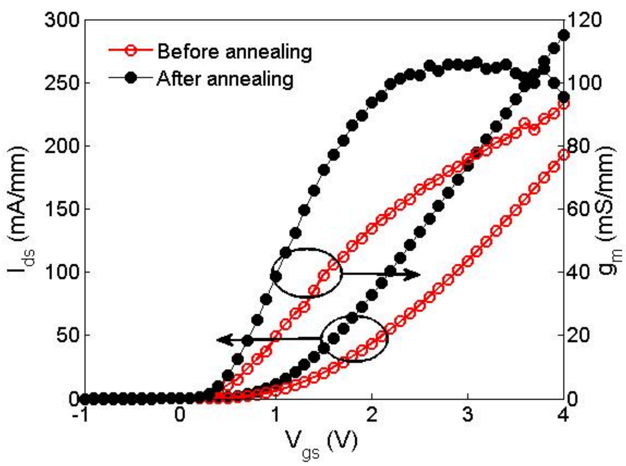

Fig. 4: Transfer characteristics of H-treated HEMTs before and after 30 min 170 °C annealing (V_{ds}= 5 V). An increase of g_m and I_{ds} is observed after the annealing.

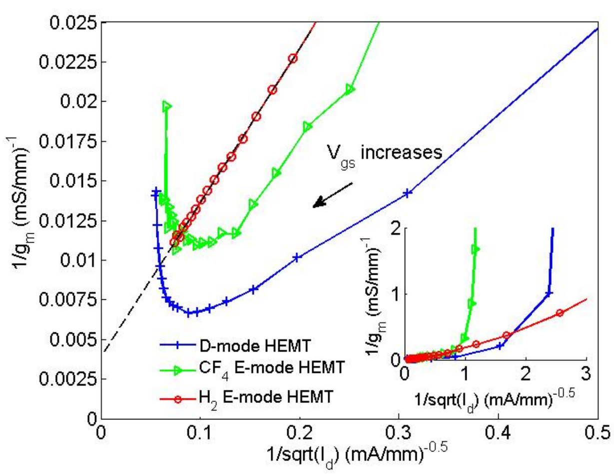

Fig. 5: $1/g_m$ vs $1/\sqrt{I_{ds}}$ of the different samples studied in this paper (V_{ds}= 5 V) The H_2-treated E-mode HEMT shows more ideal (i.e. linear) characteristics than the D-mode and CF_4 treated E-mode HEMTs. The inset figure shows the same characteristics in a larger range of I_d.