p-GaN/AlGaN/GaN High Electron Mobility Transistors

R. Coffie, S. Heikman, D. Buttari, S. Keller, A. Chini,
L. Shen, N. Zhang, A. Jimenez, D. Jena, and U. K. Mishra
Department of ECE, University of California, Santa Barbara, CA 93106
Tel: 805-893-5936, Fax: 805-893-8714, rcoffie@ece.ucsb.edu

Despite the considerable improvement in GaN-technology and material quality, RF-dispersion is still one of the main issues hampering device progress. RF-dispersion affects device output power and device power added efficiency (PAE) due to a reduction in saturation current and an increase in knee voltage at high frequencies and high biases. Surface passivation, using silicon nitride, has been found to mitigate RF-dispersion and microwave power degradation [1-3]. This paper discusses a novel AlGaN/GaN high electron mobility transistor (HEMT) device structure has been developed to reduce RF-dispersion prior to silicon nitride passivation. The material structure and device cross-section are shown in Fig 1. The device structure uses a p-doped GaN cap layer to screen surface potential changes (regardless of origin) from affecting the gate-drain access region resistance (see Fig. 2), reducing the amount of RF-dispersion in the device.

The epilayers of AlGaN/GaN devices were grown by metal organic chemical vapor deposition (MOCVD) on a c-plane sapphire substrate. Sheet electron concentration and electron Hall mobility of the as-grown wafer were $\sim 1.35 \times 10^{13}$ cm^{-2} and 1,475 cm^2/V-s at room temperature.

Devices were fabricated with Ti/Al/Ni/Au ohmic contact formation, mesa isolation, reactive ion etching (RIE) gate recess, Ni/Au/Ni gate schottcky contact, and RIE removal of the Mg-doped GaN layer between the gate and source access region. All layers were defined by i-line stepper lithography.

The common source DC characteristics are shown in Fig.3 (a). The saturation current, I_{max}, is about 1.0 A/mm and pinch-off voltage is –5V. The peak value of extrinsic transconductance, g_m, is about 205 mS/mm. Three-terminal catastrophic breakdown voltage is 50 V. Pulsed I_{max} comparison produced by pulsing the gate from pinch-off to open-channel conditions for different pulse widths is shown in Fig 3 (b). No dispersion is seen for 80 µsec pulses, but the 200 nsec I_{max} curve does show an increase in knee voltage of about 3 V. The small amount of dispersion seen at 200 nsec is due to the unscreened surface located between the gate and drain recess side-wall. DC to 40GHz device S-parameters were measured at a V_{DS} of +15V, I_{DS} of 295 mA/mm. Figure 4 (a) shows the h_{21} and unilateral power gain (UPG) of a typical device resulting in an f_t of 20 GHz and f_{max} of 38 GHz. RF continuous wave (*CW*) power measurements were performed on uncooled devices on a sapphire substrate at 4.2 GHz. Figure 4 (b) shows the unpassivated power performance of the devices biased at a V_{DS} of +20V. The output power density is 3.0 W/mm. The small-signal gain, power-added efficiency (PAE), and large-signal gain are 17 dB, 40% and 9.5 dB, respectively. Typical unpassivated output powers for an $Al_{0.35}Ga_{0.65}N$/GaN HEMT are less than 1 W/mm. Further improvement in device performance is expected after SiN passivation.

We believe devices that use a combination of epi-layer and surface passivation control of RF-dispersion will ultimately give the reproducibility AlGaN/GaN HEMTs need to become a commercial product.

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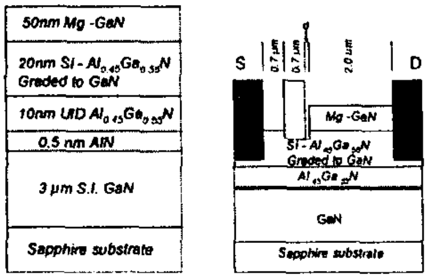


(a) (b)

Fig. 1. (a) Material structure grown by MOCVD. Si doping in graded layer ~ 1.3 x 10^{19} cm^{-3}; Mg doping in cap layer ~ 10^{20} cm^{-3}. (b) Cross-section of fabricated device.

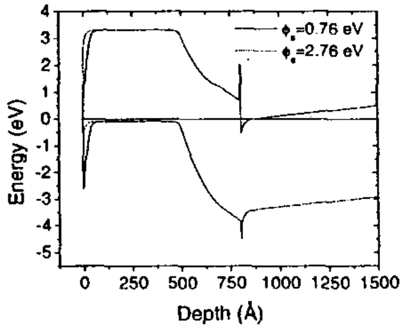
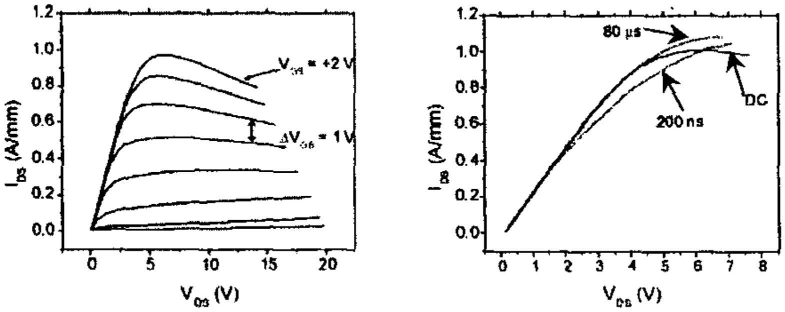
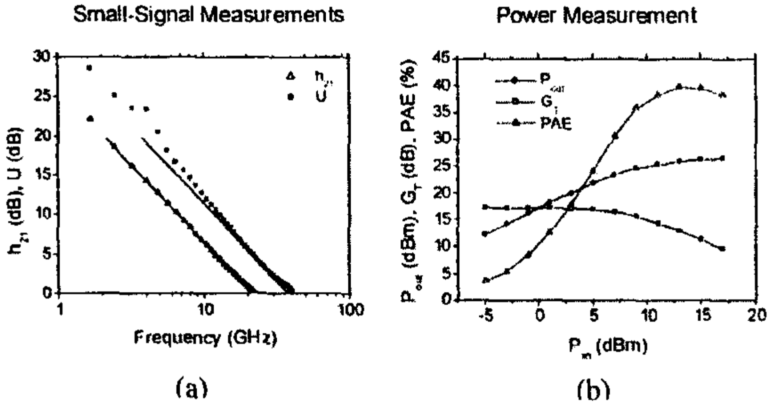


Fig 2. Band diagram of p-GaN/AlGaN/GaN HEMT. A 2 eV change in surface potential produces no change in channel charge. For a conventional $Al_{0.35}Ga_{0.65}N$/GaN HEMT, a 2 eV change in surface potential reduce the channel charge by 20 %.



(a) (b)

Fig. 3. Unpassivated 150 μm device with L_G = 0.7 μm. (a) Output characteristics. (b) I_{max} comparison for different pulse widths; 80 μsec and 200 nsec. No dispersion seen at 80 μsec, but small amount of dispersion seen with 200 nsec pulse.



(a) (b)

Fig. 4. Unpassivated 150 μm device with L_G = 0.7 μm. (a) h_{21} and unilateral power gain plots. Bias conditions: V_{DS} =15 V; I_{DS} = 295 mA/mm. f_t = 20 GHz, f_{max} = 38 GHz. (b) Power measurements at 4.2 GHz. Bias conditions: V_{DS} =20 V; I_{DS} = 150 mA/mm. Maximum Pout = 3 W/mm; Peak PAE = 40 %.