Fabrication of GaN Quantum Well HEMTs

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Primary CNF Tools Used: Autostep i-line stepper, PT770, Oxford 81, e-beam evaporator (odd and even), AFM Veeco Icon, Oxford PECVD, Oxford FlexAL, JEOL 6300, Glen 1000 resist strip, Zeiss Ultra/Supra SEM, profilometers, photolithography spinners/hotplates, solvent and acid hoods

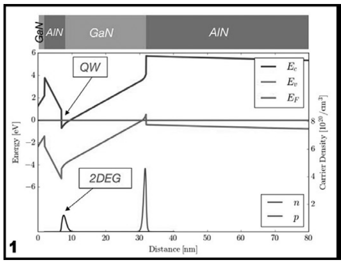
Abstract:

This work focuses on the fabrication and characterization of gallium nitride quantum well HEMTs (QW HEMTs) and GaN pFETs based on the aluminum nitride platform. QW HEMTs provide numerous advantages over the conventional AlGaN/GaN HEMT, including: improved carrier confinement, higher thermal conductivity, and improved reliability at high voltages. We report high electron mobility transistors (HEMTs) with saturation current densities of 2 A/mm and breakdown fields in excess of 2.7 MV/cm. In addition, we have fabricated an operational *p*-channel field-effect transistor (pFETs) on the same AlN platform with clear gate modulation of drain current. The development of efficient pFETs on AlN could enable complementary logic functionality in nitrides.

Summary of Research:

The QW HEMT offers a wealth of potential for new transport phenomena in III-V nitrides, as well as several improvements to the conventional AlGaN/GaN HEMT that will allow for improved performance at the limits of high power and high frequency. Our group has previously grown and fabricated QW HEMTs [1-3] with heterostructures currently being grown via MBE at Cornell. The quantum well HEMT structure consists of an AlN buffer (500 nm), GaN channel (30 nm), AlN barrier (5 nm), and a GaN passivation layer (2 nm).

The first component of our fabrication process is MBE-regrown ohmic contacts. To prepare the sample for regrowth, several depositions and etches are performed with CNF equipment. The as-grown sample is cleaned in CNF with acetone, IPA, nanostrip, HF, and HCl. SiO_2 (Oxford PECVD) and chromium (e-beam evaporator) are then deposited on the sample as hard masks. Photolithography (Autostep) is used to pattern the desired regrowth areas. The chromium and SiO_2 are etched (PT770 and Oxford 81). Finally, the sample is etched to expose the 2D electron gas (2DEG) for regrowth of ohmic contacts. By using the tools available in the CNF, we have achieved 2DEG contact resistances as low as 0.25 Ohm mm.



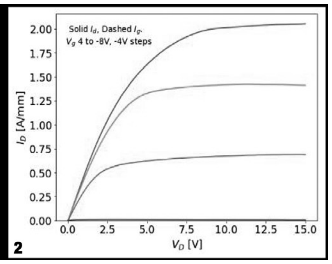


Figure 1, left: *The energy band diagram of the GaN quantum well HEMT with electron and hole concentrations.* ***Figure 2, right:*** *(a) IDVD for quantum well HEMT.* $L_g = 1.5\ \mu m$.

Once the ohmic contact is established via MBE regrown n++ GaN, the regrowth is measured via atomic force microscopy (Veeco AFM) to characterize the quality of the GaN. The devices are isolated via i-line lithography and dry etched to ensure proper device dimensions. Ohmic contact metal are is defined by i-line lithography, and are deposited via e-beam evaporation. This is followed by gate contacts defined by both i-line lithography and EBL (JEOL 6300), and deposited with e-beam evaporation.

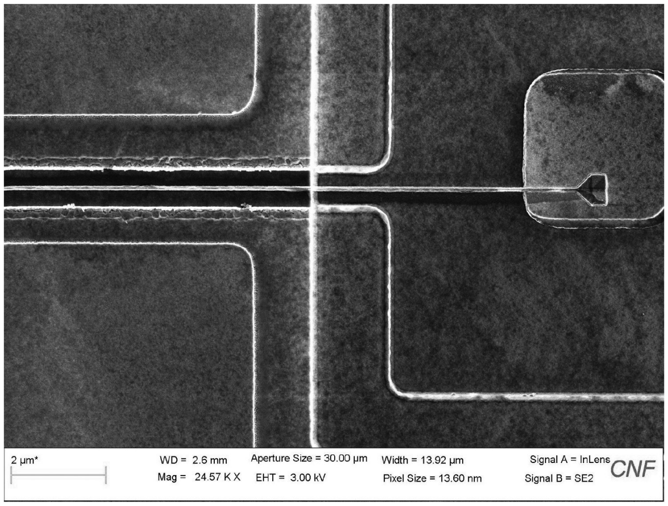


Figure 3: SEM image of a processed RF device. $L_g = 100$ nm.

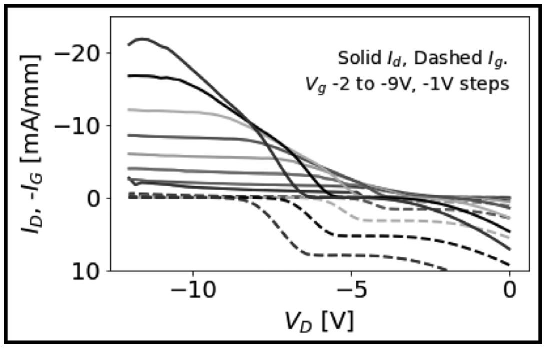


Figure 4: pFET IDVD with clear modulation of drain current. Significant gate leakage limits the device.

Finally, the devices are passivated by combinations of SiN, AlN, and Al_2O_3 via ALD (Oxford FlexAL) and PECVD (Oxford PECVD). The final devices are observed via SEM (Figure 3).

In the past year, the first QW HEMT devices were processed and measured at Cornell. After initial optimization of processing, the QW HEMTs have yielded solid DC performance, with saturation currents over 2 A/mm ($L_g = 1.5$ μm) and $g_m = 220$ mS/mm, as well as $E_{breakdown}$ in excess of 2.7 MV/cm.

In the coming year, the fabrication process will be further optimized for DC and RF performance. With improvements, GaN QW HEMTs can push the limits of high frequency/high power performance of nitride HEMTs, and establish AlN as the optimal platform for the future of nitride electronics.

In addition to high-performance HEMT devices, this platform also provides a natural *p*-channel transistor option based on the hole gas at the GaN-on-AlN interface. Growths focused on optimizing this region have achieved record low 2D hole sheet resistances (below 10 kOhm/sq) for GaN-based devices and, by a similar process to the one described above, have yielded promising preliminary devices. Providing the elusive *p*-channel transistor in a wide-bandgap platform could revolutionize the device of high-power integrated circuits by enabling efficient CMOS-style topologies with compact high-voltage transistors.

References:

[1] Li, et al., "Ultrathin Body GaN-On-Insulator Quantum Well FETs with Regrown Contacts", IEEE (2012).

[2] Islam, et al., "First Demonstration of Strained AlN/GaN/AlN Quantum Well FETs on SiC", DRC (2016).

[3] Qi, et al., "Strained GaN quantum-well FETs on single crystal bulk AlN substrates", APL (2017).