Microwave and DC Performance of AlGaN/GaN HEMTs Grown on Si using a New Growth Technique

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Abstract

RF performance and improved DC characteristics were observed for GaN-based HEMTs using epitaxial layers grown on silicon via the SIGANTIC™ growth technique. The AlGaN/GaN HEMTs employed optical gate lithography ($L_g = 1\ \mu m$) in the two-finger pi configuration. Measured devices exhibited good DC performance, with maximum transconductance and current densities of 110 mS/mm and 470 mA/mm respectively. A special technique based on current injection was used for performance evaluation and drain-to-source breakdown voltages V_{DS}^{BD} ~ 25 V – 35 V were observed. Microwave characteristics for these devices were also promising, where high current gain and maximum power gain frequencies of 5.9 GHz and 12 GHz, respectively.

Introduction

Due to the recent advancements in epitaxial layer quality and device processing techniques, GaN-based HEMTs have become prime candidates for high power and high frequency applications. The large breakdown field ($F_B > 2\ MV/cm$) and carrier saturation velocity ($v_s \sim 2.0x10^7\ m/s$) of this material system allows for a definite improvement over current Si or GaAs based devices. State-of-the-art power density and high frequency performances have been observed for nitride-based HEMT devices and circuits [1], but there are still important problems to overcome. Most readily available growth substrates have a severe lattice mismatch to GaN, but materials that are more closely matched are prohibitively expensive for mass production. Often times low-resistivity ohmic contacts require high annealing temperatures, and high dislocation densities for even high quality epitaxial layers limit the ultimate performance of GaN-based HEMTs. Although device results have been reported for HEMTs using nitride materials grown on silicon (111), the layers employed suffer from epitaxial thickness limitations and the subsequent degradation in quality that results [2]. The use of the SIGANTIC growth technique [3] can alleviate these difficulties by allowing high quality growth of nitride-based material on silicon, or other low-cost growth substrates, with thicker epitaxial films and improved material quality.

In this work, we will report the fabrication and measurement of HEMTs using AlGaN/GaN layers grown on silicon by the SIGANTIC® growth technique, with very promising DC and microwave performance.

*** SIGANTIC™ is a registered trademark of Nitronex Corporation**

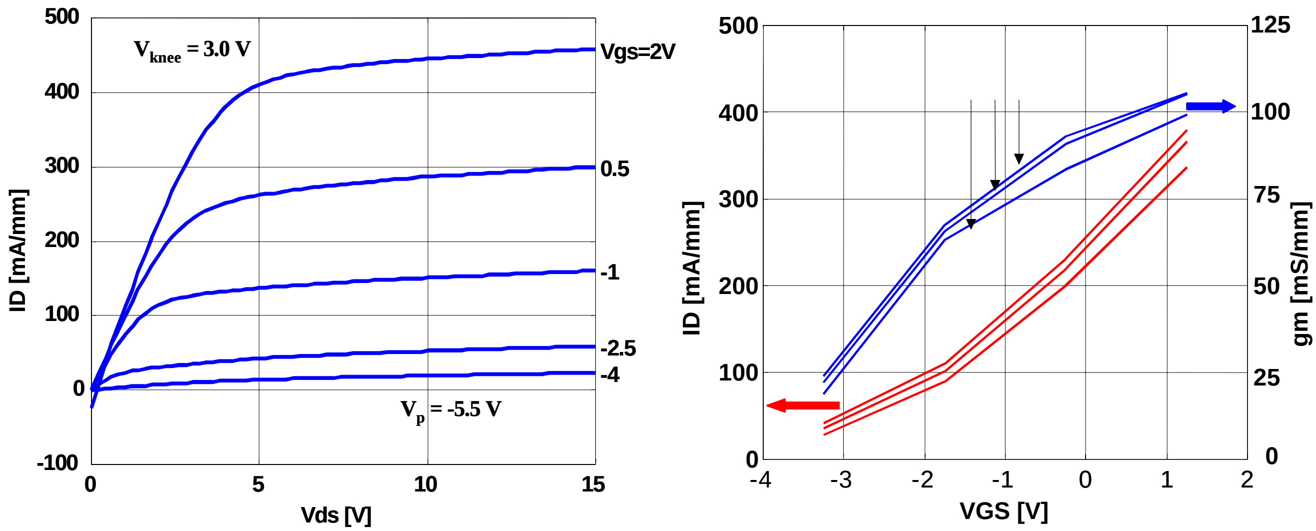

Figure 1. Normalized I_d-V_{ds} plot and DC transfer characteristic for a 1µm-gate HEMT

Device Fabrication and Ohmic Optimization

The HEMT device layers were grown on Si (111) by MOCVD using the SIGANTIC growth technique, which is described elsewhere [3]. Essentially, SIGANTIC involves an engineered process that accounts for the differences in lattice and thermal coefficient of expansion mismatch between epitaxial nitride layers and the Si (111) substrate. Thick (>2µm), crack-free epilayers can be obtained with very smooth interfaces by this technique. The device mesas were defined using reactive-ion etching (RIE), using CCl_2F_2 and Ar_2 etching chemistry. RIE etch durations, with calibrated etch rates, were chosen to produce device mesa heights around 300 nm – 350 nm for proper device isolation, and to prevent any possible discontinuity between the gate finger and gate pad across the mesa step.

Source and drain ohmic contacts were defined using optical lithography, and Ti/Al/Pt/Au metallization layers were deposited by electron-beam evaporation. Several studies were made to determine the effect of ohmic layer metal thickness, metal sequence, annealing times and temperatures and evaluate the optimum metallization scheme. As deposited the ohmic contacts had very high contact resistance and Schottky-like behavior was observed. It was also observed that for high Al content AlGaN, as compared to similarly doped/undoped GaN layers, a slightly thicker Ti layer and higher annealing temperatures were required to achieve low contact resistance.

Successive annealing steps between 800 and 950 °C were employed to improve the contact resistivity to ~ 0.5 Ω/mm. The gate Schottky contacts consisted of a Pt/Ti/Au metallization, defined through optical lithography, with a gate length of 1 µm. Test structures with devices of varying gate lengths were used to determine the quality of the deposited gates. A thick Ti/Al/Ti/Au interconnect metallization was then deposited to enable proper DC biasing and high frequency measurement using ground-signal-ground microwave probes.

DC Measurements of AlGaN/GaN HEMTs

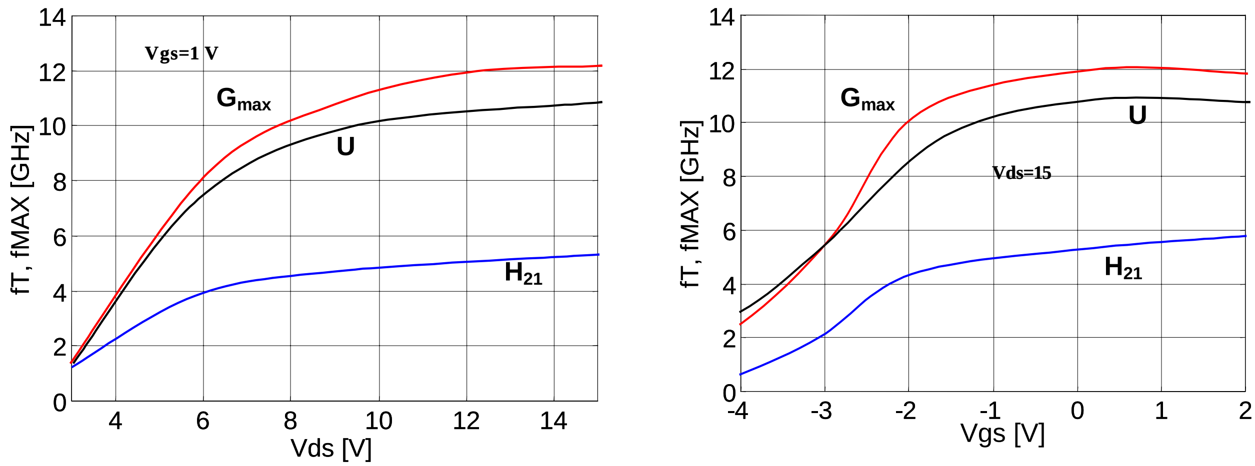

Figure 2. The effect of DC bias conditions on f_t and f_{max} values

The DC I-V transfer characteristic of a 2x75μm AlGaN/GaN HEMT are shown, in Figure 1. The device shows good current capability with a maximum current density of ~ 400 *mA/mm* with a threshold voltage V_{th} of *-5.5 V* and a low knee voltage V_{knee} of ~ 3 V. The maximum extrinsic transconductance (g_m^{ext}) of *110 mS/mm* occurs at a gate to source voltage V_{gs} of *+1 V*. The current density scales dramatically with gate width, as a 2x35 μm HEMT exhibits a maximum current density of only *120 mA/mm*, with a corresponding g_m^{ext} of *76 mS/mm*. The large difference in current densities between the large and small gate periphery devices is related to differences in ohmic contact quality for different areas across the wafer. Material uniformity was, however, good as determined by structural, optical and electrical characterization.

The evaluated characteristics represent a significant improvement over previously published DC characteristics of GaN-based FETs grown on silicon [4]. It should also be noted that the maximum values for transconductance occur at positive gate bias values as opposed to negative gate bias values for most other reported GaN HEMT results. The drain-to-source breakdown voltage, V_{DS}^{BD}, was measured using a special technique based on current injection, which is described elsewhere [5]. We observed V_{DS}^{BD} values ~ 25 V – 35 V consistently among devices of different gate peripheries and across the wafer. The on and off-state breakdown measurements indicate that the primary breakdown mechanism for these devices is gate, rather than channel breakdown related.

High-Frequency Characterization of AlGaN/GaN on Si HEMTs

Small signal, on wafer S-parameter measurements of the fabricated microwave HEMTs were performed using an HP 8510 S-parameter measurement tool in automated setup and an HP 4145B as the DC bias source. The current gain (f_t) and maximum power gain cutoff frequencies (f_{max}) were extracted from the S-parameter data for several DC bias points. Devices exhibiting superior DC characteristics also had superior high frequency performance. Just as observed by DC measurements, the areas on the wafer that displayed the highest ohmic contact quality also contained the devices that displayed the best high frequency performance.

The high-frequency characteristics of a 2x75μm AlGaN/GaN HEMT are shown, in Figure 2. The curves display the bias dependent values of f_{max} as obtained from Maximum Available Gain (G_{max}) and Unilateral Gain (U) measurements and f_T as obtained from Current Gain (H_{21}). The maximum f_t value obtained was 5.9GHz. We observed that the peak value of 12GHz for f_{max} occurs at a gate to source voltage V_{gs}, of *+1V* and a drain to source voltage V_{ds} of *+15 V*, while *ft* improves only slightly for larger positive gate values. Under fixed gate bias conditions, f_t and f_{max} values show a dramatic increase for Vds from *+3 V* to *+6 V*, but level off and show gradual improvement for $V_{ds} > +10$ V. This allows for flexibility in choosing device and circuit bias points for circuit designers using these devices. As observed during DC characterization of the devices, the best values for f_t and f_{max} occur at the same bias points for g_m^{ext}. It is expected that that these devices would experience little dispersion in the value for g_m^{ext} and R_{ds}. These good high frequency results for an optical lithography 1-μm gate process are very promising for the use of GaN-based device layers on silicon substrates.

Conclusions

We have demonstrated the first realization of 1-μm gate process AlGaN/GaN HEMTs from device layers grown on silicon using the SIGANTIC growth process. The maximum current density and extrinsic transconductance values observed are ~ *400 mA/mm* and *110 mS/mm* respectively. DC I-V curves exhibit well defined linear and saturation regions, with low threshold and knee voltage of $V_{th} = -5.5\ V$ and $V_{knee} = +3V$ respectively. Drain-to-source breakdown voltages, V_{DS}^{BD} of *25V – 35V*, using the current injection technique, were also observed for the measured devices. Maximum values of the current and power gain cutoff frequencies of $f_t = 5.9\ GHz$, and $f_{max} = 12\ GHz$, were observed at $V_{gs} = +1$ and $V_{ds} = +15\ V$. Significant improvements in DC and high-frequency performance are expected with the use of submicron gates and improved ohmic contacts.

Acknowledgement

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