11.9 W output power at 4 GHz from 1 mm AlGaN/GaN HEMT

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A high electrical breakdown field combined with a high electron saturation velocity make GaN very attractive for high power high frequency electronics. The maximum drain current densities of AlGaN/GaN HFETs range from 1.0 A/mm to 1.5 A/mm [1-3]. Hence, it is obvious that breakdown voltages over 160 V are required to achieve record output power densities larger than 30 W/mm [3] for class A operation. Maximum RF output power of GaN based HEMTs is significantly less than what can be estimated from its DC characteristics, the so-called DC to RF dispersion [4]. This gate lag effect and a good passivation of the AlGaN surface under the gate contact are key elements in achieving high power HEMTs.

In this paper we present an optimized process for fabrication of dispersion-free small (Wg = 80 μm) and large (Wg = 0.25 mm, 0.5 mm, and 1.0 mm) gate periphery n.i.d. AlGaN/GaN HFETs grown by MOVPE on s.i. 4H-SiC substrates.
First small periphery devices were fabricated on three epi-structures all having 30nm undoped $Al_{0.3}Ga_{0.7}N$ barrier layer: two using a very thin (1-2 nm) undoped AlN with undoped GaN buffer layer (1.2 μm) and one using a Fe-doped semi-insulating (s.i.) GaN layer.

The DC to RF dispersion and the gate leakage were solved by applying by combining:

- an adequate treatment consisting of a low-power Ar-plasma after the ohmic contacts (source and drain).
- a cleaning in a NH_4OH solution (1 min) just before the Schottky metallization. The ammonia dip counted for a substantial gate leakage reduction from 6.7 mA/mm down to 0.4 mA/mm.
- the use of an optimized SiN_x passivation layer.

DC (I-V) data of the small periphery HFETs show the potential for high-power performance of these devices as they enable both large drain current and drain-source voltage swings. The former can be realized because of the high maximum drain current densities, typically 1.0 A/mm, and the low values of $I_{G,leak}$ and $I_{D,leak}$ at pinch-off, which are typically 200 μA/mm and 2 mA/mm, respectively for large gate periphery devices.

The large voltage swing is enabled by the low value of V_{knee}, typically 4 V - 6 V, and the high value of $V_{BD,off}$, typically larger than 150 V, which is enabled by the incorporation of T-gates with a field plate (FP) length of 0.25 μm. To be noticed that the best performance was obtained with HEMTs making use of the iron (Fe) compensation doped s.i. GaN buffer layer. Hence, only this structure has been used to fabricate large gate periphery devices whose microwave power performance as a function of Wg has been investigated.
For small devices with an L_g of 0.7 μm the values for f_T and f_{max}, which have been extrapolated from small-signal S-parameter measurements, were 12 GHz and 34 GHz, respectively. These values indicate that devices with these gate lengths are suitable for S-band (2 GHz - 4 GHz) applications.
Single tone CW active load-pull results of small gate periphery (Wg = 80 μm) devices with a gate length of 0.25 μm at 10 GHz have demonstrated the successful elimination of gate lag from devices on all epitaxial layer structures used. This result proved the successful integration of the developed surface passivation modules, i.e. the Ar-plasma surface treatment, the NH_4OH dip and the SiN_x surface passivation into one process.

Single tone CW and pulsed active load-pull results at 2 GHz under class AB bias conditions, e.g. V_{DS} = 50 V and V_{GS} = -4.65 V, have shown excellent values for P_{out} of large gate periphery AlGaN/GaN HFETs on the Fe-doped epi-structure i.e. 11.9 W for a 1.0 mm T-gate HEMT. Moreover, excellent scaling of P_{out} with W_g has been demonstrated for equally biased devices with the same type of gate, i.e. T- or FP-gate. Although L_{FP} does not seem to influence the value for P_D, it can be observed that G_p decreases for increasing L_{FP} because the value of C_{gd} increases with L_{FP}. In addition, the values for G_p, typically 15 dB, and PAE, typically larger than 54 %, clearly show that these power HEMTs in combination with the optimized process are very well suited for application in high power amplifiers. Single tone pulsed active load-pull measurements at 4 GHz under class AB bias conditions, e.g. V_{DS} = 50 V and V_{GS} = -4 V, have shown similar results. In addition, as the devices have been measured over a period of 5 months, it has clearly been shown that This performance is stable over time.
Comparison of the maximum output power densities at S-band as a function of total gate width of n.i.d. AlGaN/GaN HFETs on s.i. SiC substrates that we have shown to results reported in literature, clearly shows that we have achieved state-of-the-art power HEMTs.

References

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