Noise Figure Measurements and Modeling of Field-Plated AlGaN/GaN HEMTs

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AlGaN/GaN HEMTs have received a great deal of attention due to impressive reported microwave powers. Field-plating has made possible the high-power densities that are now common. The microwave noise results are also very good [1]. A field plate *reduces* the noise of the device, resulting in a better Noise Figure (NF). This is not well understood, nor has gate leakage's effect on noise in GaN been studied. This talk will be broken into several parts. We will first show that gate leakage plays an important part in the noise figure of GaN HEMTs through measurements and modeling. Then NF measurements of field-plated devices of different gate length and varying field-plate length will be investigated. Modeling will then be applied to non-field-plated and field-plated devices. Finally, we compare GaN HEMTs to GaAs HEMTs for noise figure after extracting extrinsic parasitics and scaling for gate width.

The AlGaN/GaN samples were grown by MOCVD on a c-plane SiC substrate. The epitaxial structure on the substrate is an AlN nucleation layer, a semi-insulating Fe-doped GaN-base layer, an unintentionally-doped GaN layer, and finished with an $Al_{0.27}Ga_{0.73}N$, silicon-doped, barrier layer. The gate lengths (L_g) of the devices are 0.7 μm and 0.15 μm and the widths 150 μm. The L_g 0.7 μm devices have a field-plate length from 0.5 μm to 1.1 μm. The GaAs samples are from a Triquint foundary process.

Devices with different gate leakage can be hard to compare. We have found that a leakage of more than a few micro-amps causes the noise figure to significantly increase. For example, a device with a gate leakage of 21 μA has a 1.83dB NF at 10 GHz, but a device with 141 μA of gate leakage has an NF of 2.6dB. Therefore, when comparing devices from different samples, one must take account of their gate leakages. The small-signal parameters vs. bias for the field-plated devices are extracted and compared to non field-plated devices. This is then used in the NF modeling. Three different models are applied to the different devices: Pucel [2], Pospieszalski [3], and van der Ziel [4]. A gate leakage term has been added to the van der Ziel modeling for better accuracy. This model shows that gate resistance alone does not explain why field-plating gives better noise performance, as it only explains a 0.1 dB difference and not a 0.3 dB difference. Ongoing work includes more complex modeling to explain this difference.

In conclusion, a combination of modeling and experimental measurements have been used to understand the NF of AlGaN/GaN HEMTs. Both gate leakage and field plate are very important in these devices' NF and need to be correctly modeled to have accurate noise figure prediction.

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[2] R. A. Pucel, H. A. Haus, and H. Statz, "Signal and noise properties of Gallium Arsenide Microwave Field-Effect Transistors," in *Advances in Electronics and Electron Physics*, vol. 38, 1975, pp. 195-265.

[3] M. W. Pospiezalski, "Modeling of noise parameters of MESFET's and MODFET's and their frequency and temperature dependence," *IEEE Transaction on Microwave Theory and Techniques*, vol. 37, pp. 1340-1350, Sept. 1989.

[4] A. Van Der Ziel, "Gate noise in field effect transistors at moderately high frequencies," *Proc. IEEE*, vol. 51, pp. 461-467, Mar. 1963.

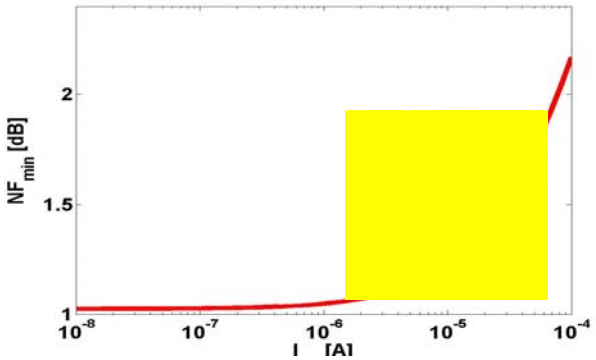

Fig 1. Modeled NF against I_{gs} for non-field-plated 0.7 µm devices at 5GHz. The yellow box shows the typical range for GaN HEMTs.

Field Plate Length [µm]	0	0.5	0.7	0.9	1.1
Nf_{min} [dB]	1.16	0.985	1.1	0.941	0.894

Table I. Variation in NF with field-plate length for 0.7µm devices at 5GHz

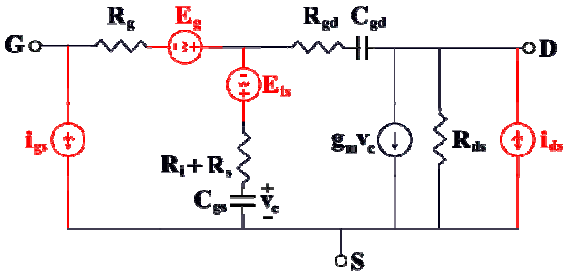

Fig 3. Simplified small-signal model with van der Ziel noise modeling that includes gate leakage.

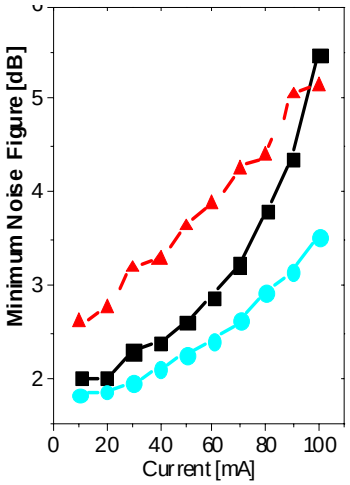

Fig 2. Variation in NF for non-field-plated devices having L_g 0.7 µm with low (cyan), higher (black), and high (red) gate leakage. Measurements at 10GHz

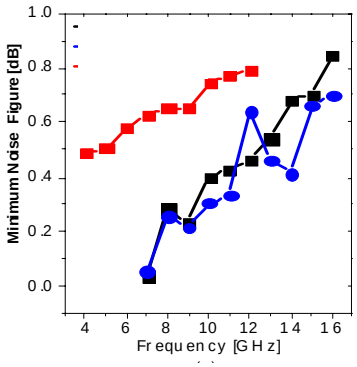

Fig 4. Measured field-plated (black and blue linse) and non-field-plated (red line) NF for Lg 0.15 µm devices.

Sample	1	2	3	4	5	6
Measured						
Nf_{min} [dB]	1.14	1.13	1.1	1.16	1.15	1.18
I_{gs} @ Nf_{min} [µA]	5	11	6	14	13	14
Modeled						
Nf_{min} [dB]	1.17	1.34	1.15	1.19	1.19	1.12
Modeled but with I_{gs} = 0						
Nf_{min} [dB]	1.05	1.15	1.02	0.887	0.902	0.828

Table II. Measured, modeled (with van der Ziel model), and modeled without gate leakage at 5GHz with non-field-plated Lg 0.7 mm devices from 6 different samples.