Low Frequency and Microwave Noise Characteristics of GaN and GaAs-based HFETs

J. Deng, T. Werner, M. S. Shur, R. Gaska**, Asif Khan*, G. Simin*, and J. W. Yang*

CII 9015, Rensselaer Polytechnic Institute
110, 8th Street, Troy, NY 12180

*Department of Electrical Engineering, University of South Carolina
** Also with Sensor Electronic Technology, Inc. Latham, NY 12110

Phone: (518) 276-2720, email: dengj@rpi.edu

Abstract:

In this paper, we compare the low frequency and microwave noise characteristics of GaAs-based transistors and emerging GaN-based devices. At this time, GaAs transistors can achieve up to now smaller noise figures than GaN HFETs, but the optimum bias condition for lowest noise is found for a lower drain voltage as for the analyzed GaN devices. The resulting higher gain can have a positive impact on the overall performance of the system noise figure. We also studied the 1/f noise of the GaN transistors. No correlation between the microwave noise and the flicker noise was found, which indicates that the two noise types have different origins and can thus be linked to two uncorrelated noise mechanisms.

INTRODUCTION

Low frequency and microwave noise characteristics of Heterostructure Field Effect Transistors (HFETs) are very important for microwave applications of these devices. The level of 1/f noise is an established measure of materials and device quality and a good predictor of device reliability. The 1/f noise also directly affects the level of phase noise. In this paper, we will compare the low frequency and microwave noise characteristics of GaAs-based transistors and emerging GaN-based devices.

Microwave noise models are quite helpful in understanding the noise sources inside the transistor, which might contribute to the low-noise amplifier circuit design. The noise model by Pucel et al [1] and by Pospieszalski [2] is the most popular among equivalent circuit noise models. The first of these models is based on the device equivalent circuit with three parameters, which describe the gate noise source, drain noise source and the correlation between the gate and drain noise, respectively. Pospieszalski's model reduces the number of the additional noise parameters to two: T_d and T_g, which are the drain and source noise temperatures, respectively. [2] The application of Pospieszalski's model to GaAs based HFETs showed that T_d has a strong dependence on the drain current (for a fixed drain bias), while T_g can usually be kept at room temperature. [3]

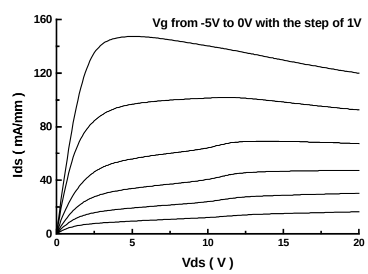
Recently reported minimum noise figures of 1.06dB for 0.25micron, 0.6dB for 0.15micron [4] and 0.53dB for 0.12micron [5] (all at 10GHz) gate length devices demonstrate a high potential of AlGaInN/GaN HFETs as low noise microwave devices. These figures are comparable to GaAs commercial super low-noise HFETs, which demonstrated a noise figure of 0.4dB at 10GHz for 0.15µm device. [6] In this paper, we report on the noise measurements of AlGaN/GaN-based HFETs, on the interpretation of the measured data using Pospieszalski's model and on the studies of the 1/f noise of the same devices.

DEVICE FABRICATION

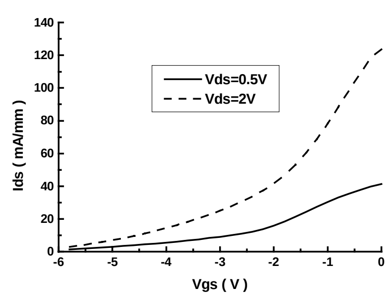
The device epilayer structure was grown by low-pressure Metal Organic Chemical Vapor Deposition (MOCVD) over sapphire substrates. The heterostructure consisted of a 1µm insulating GaN layer capped with a 30nm $Al_{0.2}Ga_{0.8}N$ barrier layer, which was doped with silicon approximately to $2x10^{18}cm^{-3}$. The gate length of the devices was 2µm. Hall mobility and carrier concentration were $1100cm^2/Vs$ and $8x10^{12}cm^{-2}$, respectively.

DC CHARACTERISTICS

Fig. 1 shows the DC characteristics of the device described above, with 2µm of gate length and 2x70µm gate width. From Fig. 1 (c), we can see that the gate leakage current is too low to affect the drain current. The estimated threshold voltage of the device is around –5.9V.



(a)



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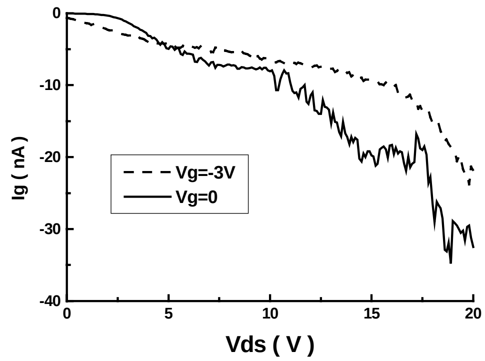
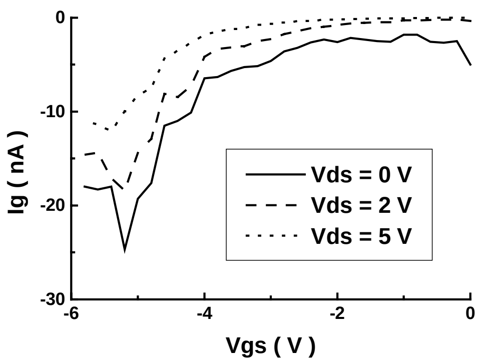


(c)



(d)

Fig. 1 DC characteristics of the AlGaN/GaN HFET (a) Drain Current versus drain bias (b) drain current versus gate bias (c) Gate leakage current versus drain bias (d) Gate leakage current versus gate bias characteristics

MICROWAVE NOISE PERFORMANCE

In order to simulate the device small signal microwave performance, we used the equivalent circuit with the noise temperatures, T_d and T_g, are linked with the input resistance R_i and the output conductance G_{ds}, respectively (Fig. 2). For GaAs-based microwave HFETs, T_d lies in the range of several thousand degrees centigrade, depending on the gate and drain bias, while T_g is much closer to room temperature. [3].

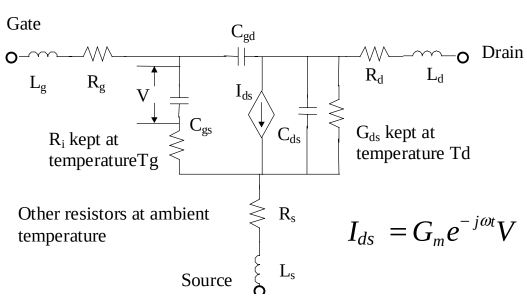


Fig. 2 Small-Signal Equivalent Circuit for HFETs

A small signal measurement was performed prior to the noise measurement. The highest cutoff frequency for the device was measured to be 3.97GHz. A close fitting was obtained between the measured and simulated S-parameters. (See Fig. 3)

The microwave noise figure for a FET is given by:

$$NF = NF_{\min} + \frac{4R_N}{Z_0} \frac{\left|\Gamma_s - \Gamma_{opt}\right|^2}{\left(1-\left|\Gamma_s\right|^2\right)\left|1+\Gamma_{opt}\right|^2},$$

where Γ_s is the source reflection coefficient presented to the input port, NF is the noise figure of the amplifier, and NF_{min} is the minimum noise figure. Z_0 is usually 50Ω, Γ_{opt} is the optimum source reflection coefficient, at which the minimum noise figure can be achieved, and R_N indicates how sensitive the noise figure is influenced by the conditions at the source.

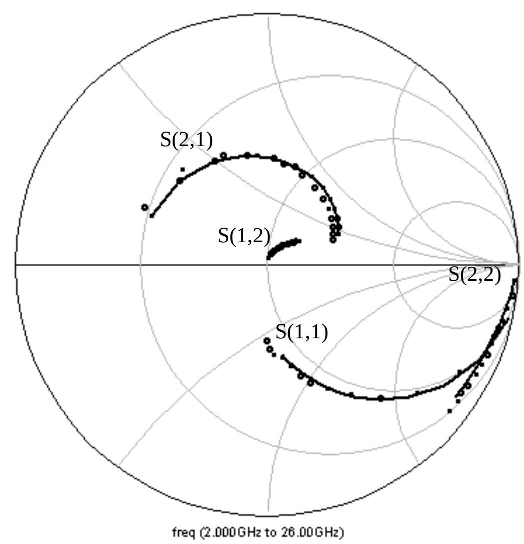
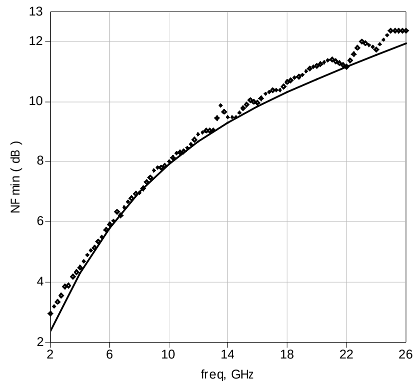


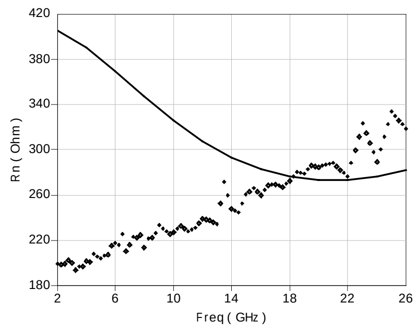
Fig. 3. Comparison of the measured and modeled small-signal performance of the AlGaN/GaN HFET (Symbol: Experiment, Line: Simulation)

Noise parameters NF_{min}, R_N and Γ_{opt} were measured in the frequency range from 2 to 26GHz. The noise figure close to 2dB was observed at around 2GHz. (see Fig. 4).

At this time, GaAs transistors can achieve up to now smaller noise figures than GaN HFETs, but the optimum bias condition for lowest noise is found for a lower drain voltage as for the analyzed GaN devices. The resulting higher gain can have a positive impact on the overall performance of the system noise figure.



(a)



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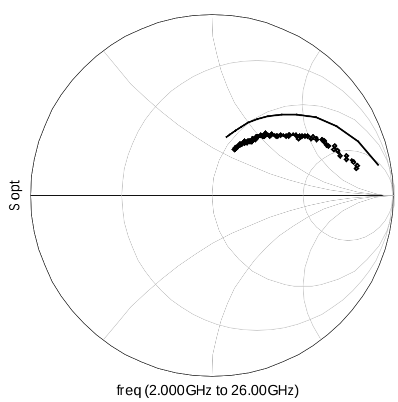

(c)

Fig. 4. Measured and simulated minimum noise performance (a) Minimum noise figure (b) R_n (c) Γ_{opt}. (Symbol: Experiment, Line: Simulation)

In Fig. 5, we show the bias dependence of the minimum noise figure NF_{min} for a GaN HFET with 0.25 µm gate length at 2 GHz at room temperature. It can be seen, that NF_{min} is decreasing for increasing drain voltages V_D, and decreasing gate voltages V_G. Also, the GaN transistor measured here shows minimum noise figure at drain voltage of around 10 Volts, which is much higher than the maximum voltage of around 3Volts in GaAs transistors. This might be due to a higher breakdown field in GaN transistors. If V_G approaches the pinch-off voltage, the minimum noise figure sharply increases (not shown in the diagram). If V_D approaches the drain source breakdown voltage, the noise figure increases as well.

Fig. 6 shows the bias dependence of the associated gain G_a for the same transistor. It can be seen that the gain is dropping quickly for decreasing drain voltages while the gate bias dependence is very weak.

1/f NOISE PERFORMANCE

Fig. 7 shows an example of a flicker noise measurement for a bias condition in the linear region of the transistor. The relative spectral current noise density S_I/I^2 is plotted versus frequency from 1 Hz to 100 kHz and the slope of the noise spectrum demonstrate a $1/f^{\gamma}$–dependence with $\gamma = 1$. In general over all measurements the exponent varied from 0.9 to 1.4. The Hooge parameter for this device is thus calculated to be 0.056.

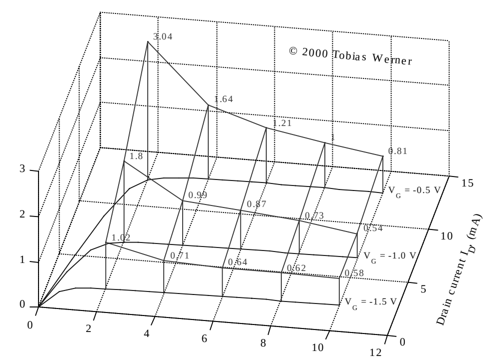

Fig. 5 Bias dependence of the minimum noise figure NF_{min}.

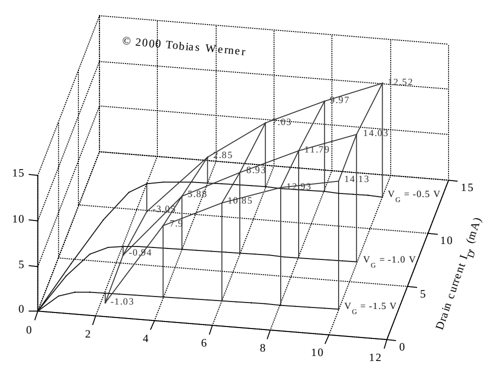

Fig.6 Bias dependence of the associated gain at minimum noise figure G_a.

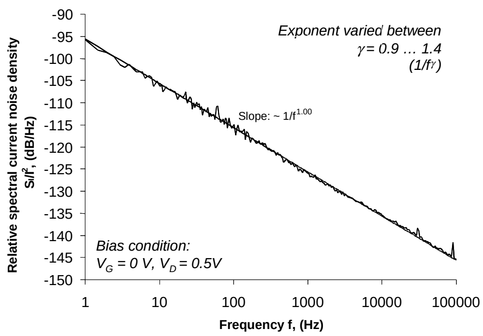

Fig. 7. Typical flicker noise measurement result with the slope of the noise spectrum proportional to 1/f.

CORRELATION BETWEEN MICROWAVE NOISE AND 1/f NOISE

The correlation between the flicker noise and the microwave noise was investigated. The minimum noise figure NF_{min} at 2 GHz, expressing the microwave noise, was compared with the relative spectral current noise density S_I/I^2 at 100 Hz, expressing the flicker noise, for an identical bias condition at room temperature. (See Fig. 8) No correlation between the microwave noise and the flicker noise was found, which indicates that the two noise types have different origins and can thus be linked to two uncorrelated noise mechanisms.

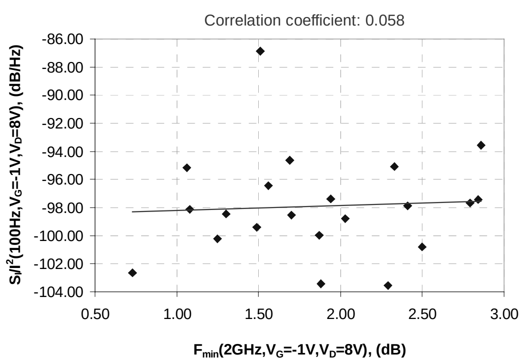

Fig. 8 Scatter diagram to analyze the correlation between the microwave and the flicker noise.

CONCLUSIONS

We presented small-signal and noise equivalent model for AlGaN/GaN based HFETs. The simulation based on these models are in good agreement with our experimental data. We also discussed the differences between GaN and GaAs based HFETs. Correlation between microwave and low-frequency noise was investigated and the results showed that the two noise types have different origins and can thus be linked to two uncorrelated noise mechanisms.

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