High-Frequency Noise in AlGaN/GaN HFETs

S. Nuttinck, E. Gebara, J. Laskar, and M. Harris

Abstract—**We present in this letter the benefits of GaN-based electronic devices for low-noise MMICs. A temperature-dependent two-temperature noise model for AlGaN/GaN HFETs is implemented on a wide range of bias conditions. This study enables to access the device high-frequency noise parameters, and allow a comparison of the noise performances with SiC and GaAs technologies.**

***Index Terms*—AlGaN/GaN HFETs, modeling, noise.**

I. Introduction

GaN POSSESSES a combination of material properties that are attractive for the fabrication of high-power microwave electronic devices [1], [2]. GaN-based transistors offer power densities up to 10 W/mm [3] and cutoff frequency above 70 GHz [4]. One of the primary uses of GaN-based transistors is to replace actual GaAs-based and vacuum-tube-based microwave power amplifiers modules in high-power applications. However, AlGaN/GaN HFETs can also be used for low-noise amplifiers (LNA). Due to the inherent high breakdown voltage of GaN-based transistors, such low-noise devices could operate reliably without limiter devices, which would significantly decrease system noise figure and further enhance system performance. In this case, models that predict the device noise performance are important for optimum designs [5]. Also, models like the two-temperature noise model allows to access device parameters that enable a comparison of the high-frequency noise performances with other technologies.

In this letter, we present characterization and modeling results of high-frequency noise in AlGaN/GaN HFETs at various temperatures and bias conditions, along with a comparison of the noise performances with other technologies. In Section II, the high-frequency noise is modeled using the two-temperature model [6], and Section III compares measured and extracted high-frequency noise parameters of devices fabricated in GaN, SiC, and GaAs technology.

II. High-Frequency Noise Modeling

The studied devices are two-finger AlGaN/GaN HFETs with a total gate width (W_G) of 250 μm, and a gate length (L_G) of 0.35 μm. The measured breakdown voltage, cutoff frequency, and saturated drain-to-source current are 70 V, 30 Ghz, and 230 mA, respectively. The four noise parameters of the devices have been measured on-wafer at various bias conditions, from 2 to 12 GHz, at 100 K and 290 K, using the multiple source admittance technique. Fig. 1 presents noise figure (NF) measurement results of a device including its pad parasitic elements, at 8 GHz, with $V_{DS} = 24$ V and $I_{DS} = 90$ mA, for various source admittance, and at the two temperatures. It can be seen that the minimum noise figure ($F_{\rm MIN}$) reduces from 2.1 dB at 290 K to 0.9 dB at 100 K. Such improvement of the noise performance at lower temperatures has been reported for InP and GaAs technologies [7], [8]. It is also noteworthy that the NF is less sensitive to the source impedance terminations at low temperatures, resulting in lower noise resistance (R_N). R_N reduces by about 50% when lowering the temperature from 290 K to 100 K, which helps to optimize for higher gain condition while maintaining a good noise performance.

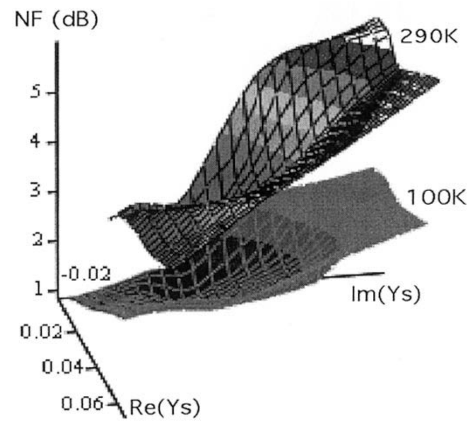

Fig. 1. Measured NF at various source admittances and at $T = 100$ K and $T = 290$ K, at 8 GHz.

The high-frequency noise in the studied AlGaN/GaN HFETs is modeled from 2 GHz to 12 GHz over a complete range of bias conditions and temperatures as thermal noise in a small-signal Hybrid-Pi equivalent circuit [6]. Because of the large current densities present in AlGaN/GaN HFETs, a two-temperature noise model is selected to predict the noise performance of the device [6]. These two temperatures are commonly referred to as gate temperature (T_G), and drain temperature (T_D). T_G and T_D are, respectively, related to the noise voltage source associated to the gate-to-source resistance (R_{GS}), and to noise current source associated to the drain-to-source resistance (R_{DS}). The expressions relating these parameters are found in [6], [7]. Accurate extraction of the device parasitic elements is crucial for precise noise modeling because it influences the determination of R_{GS} and R_{DS}. Extrinsic and intrinsic parameters are determined using conventional on-wafer extraction methods [9]–[11]. Fig. 2 shows good agreement between measured and modeled S-parameter results from 2 to 12 GHz.

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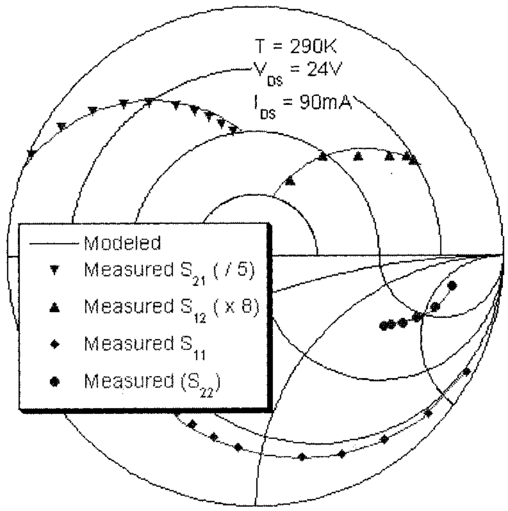

Fig. 2. Measured and modeled S-parameters from 2 GHz to 12 GHz at 290 K, $V_{DS} = 24$ V and $I_{DS} = 90$ mA.

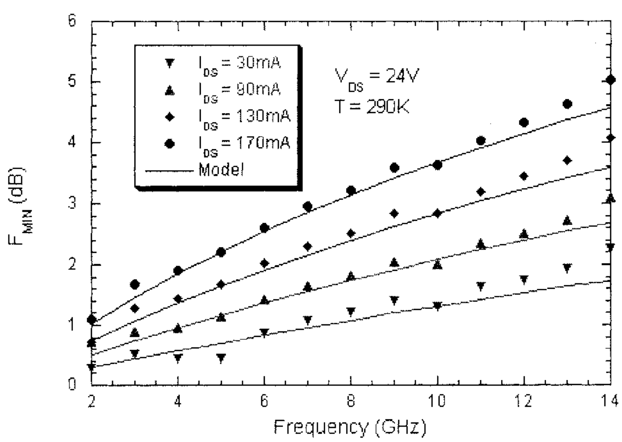

Fig. 3. Extracted and modeled F_{MIN} at various bias conditions (pad parasitics de-embedded).

The measured noise parameters contain information about the noise generated by both the active part and the pad parasitic elements of the device under test. The parasitic resistances are considered to be at ambient temperature and only contribute to the thermal noise. Their influence on the overall noise is de-embedded using the procedure introduced by Hudec [12]–[15]. The noise temperatures are then extracted by fitting the de-embedded noise parameters using a set of parameters that results in simple equations when expressed with the equivalent circuit parameters [15], [7]. Figs. 3 and 4 show good agreement between extracted and simulated noise parameters F_{MIN}, G_N, and $\mathrm{Re}(Z_{OPT})$.

The extracted noise temperatures T_G and T_D are shown in Fig. 5 for various drain-to-source current conditions and temperatures. It can be seen that both T_G and T_D increase with I_{DS}; however the relative variation of T_D is far greater than that of T_G. At a fixed temperature of 290 K, T_D increases from 2450 K at $I_{DS} = 30$ mA (13% of I_{DSS}), to 8500 K at $I_{DS} = 170$ mA (75% of I_{DSS}), while T_G increases from 650 K to 950 K. Such large increase of the drain temperature when the channel current

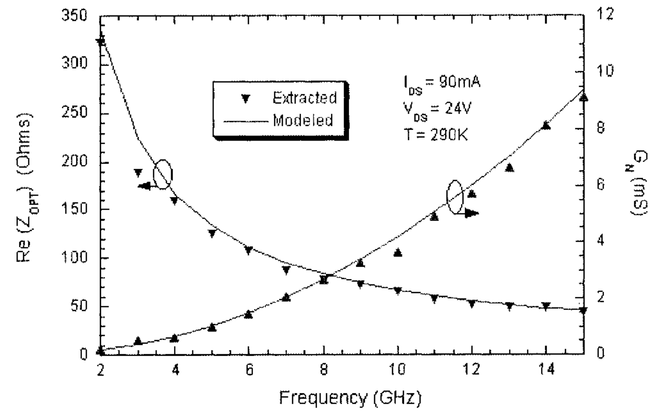

Fig. 4. Extracted and modeled G_N and $\mathrm{Re}(Z_{OPT})$.

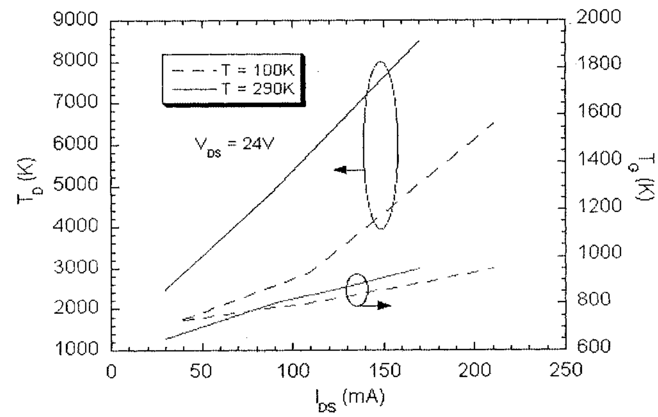

Fig. 5. Extracted T_D and T_G at various temperatures and drain-to-source current conditions.

TABLE I
COMPARISON OF NOISE PARAMETERS IN VARIOUS TECHNOLOGIES AT 10 GHz AND $I_{DS} = 50$–60% I_{DSS}

Technology	**GaAs pHEMT**	**AlGaN/GaN HFET**	**SiC MESFET**
Reference	[16]	This work	[17]
f_T (GHz)	90	30	10
R_{DS} (Ω)	106	474	2800
R_{GS} (Ω)	2.2	7	53
F_{MIN} (dB)	1	2	7
R_N (Ω)	27	30	850
T_D (K)	5500	6200	8500
T_G (K)	650	900	900

is increased toward I_{DSS} is also observed in GaAs pHEMTs [16] and SiC MESFETs [17]. The same trend is observed when the temperature of operation is lowered to 100 K. It is noteworthy that at 290 K, in the X-band, the measured F_{MIN} and R_N are between 1.2 and 3.2 dB, and 25 and 38 Ω, respectively.

III. COMPARISON WITH OTHER TECHNOLOGIES

Table I presents two-temperature noise model parameters of GaN HFET, SiC MESFET, and GaAs pHEMT. The parameters are for a frequency of operation of 10 GHz, a drain-to-source bias in the saturation region, and a drain-to-source current corresponding to about 50–60% of I_{DSS} (for the GaN and the

GaAs devices only). The extracted T_D and T_G for the studied AlGaN/GaN HFET are in the range of noise temperature obtained in other technologies, validating the modeling results. Also, it is noteworthy that lower R_{DS} and R_{GS} results in better noise performances and lower noise temperatures. The high $F_{\rm MIN}$ value for the SiC device is due to the fact that the comparison is performed at a frequency similar to its cutoff frequency. Also, the $F_{\rm MIN}$ reported for the studied GaN-based device at 10 GHz is around 2 dB and is higher that the one of GaAs pHEMT. However, it is important to mention that the cutoff frequency of typical GaAs pHEMTs is about three times higher that the f_T of the studied 0.35 μm AlGaN/GaN HFETs (30 GHz). Progress in the GaN technology has recently resulted in f_Ts above 65 Ghz, and $F_{\rm MIN}$ below 1 dB in the X-band have been reported [18], making AlGaN/GaN HFETs very good candidates for microwave low-noise applications. Also, it is noteworthy that the R_N is similar for the GaAs and the GaN technology, translating in similar degradation of the noise figure when the source impedance is moved away from the optimum termination for minimum noise.

IV. Conclusion

High-frequency noise in AlGaN/GaN HFETs is modeled at various temperatures and bias conditions. The extracted noise parameters are compared to the one of GaAs pHEMT and SiC MESFETs. The noise performances of AlGaN/GaN HFETs are comparable to the one of GaAs pHEMTs. Since GaN-based devices also exhibit high power capabilities, their use will result in limiter-free microwave transceiver, reducing the overall system noise figure.

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