Effect of gate leakage current on noise in AlGaN/GaN HFETs

S.L.Rumyantsev[1], N.Pala[1], M.S.Shur[1], M.E.Levinshtein[2], R.Gaska[3], X.Hu[4], J.Yang[4], G.Simin[4], and M.Asif Khan[4]

[1] Department of Electrical, Computer, and Systems Engineering and Center for Integrated Electronics and Electronics Manufacturing, CII 9017, Rensselaer Polytechnic Institute, Troy NY 12180-3590.
e-mail: roumis2@rpi.edu
[2] Solid State Electronics Division, Ioffe Institute of Russian Academy of Sciences, 194021, St. Petersburg, Russia.
[3] Sensor Electronic Technology, Inc., 21 Cavalier Way, Latham, NY 12110.
[4] Department of Electrical and Computer Engineering, University of South Carolina, Columbia, SC, 29208.

Low frequency noise is one of the most important characteristics of Heterostructure Field Effect Transistors (HFETs). Since HFETs are supposed to work in the wide range of gate biases, from small positive gate voltages to deep subthreshold regimes, the low frequency noise is to be small enough for the entire range of the gate voltages. In several papers, a dramatic increase of the relative spectral noise density of drain current fluctuations in AlGaN/GaN HFETs with the gate voltage has been reported [1-3]. One of the possible causes of this increase is the contribution to noise of the gate leakage current fluctuations [4,5].

We investigated the effect of the gate leakage current fluctuations on output drain current noise of GaAlN/GaN HFETs by three different techniques. First, we compare the noise properties of conventional AlGaN/GaN HFETs and novel AlGaN/GaN Metal-Oxide-Semiconductor Heterostructure Field Effect Transistors (MOS-HFETs) fabricated on the same wafer under identical conditions. In the entire range of gate voltages, the gate current in MOS-HFETs is many orders of magnitude smaller than that in identical conventional HFETs. The comparison of the noise properties of HFETs and MOSHFETs allowed us to evaluate the contribution of the gate current noise to output noise of HFETs. Second, we investigated the spectral characteristics of the gate current fluctuations in AlGaN/GaN HFETs. These results also allowed us to estimate the effect of the gate leakage noise fluctuations on noise. Third, we measured the correlation functions between gate and drain current fluctuations.

Our results show that the effect of the gate current fluctuations on output noise properties of HFETs depends on the level of noise in the AlGaN/GaN HFETs. For the transistors with a relatively high magnitude of the Hooge parameter $\alpha \sim 10^{-3}$, even a relatively high leakage current I_g ($I_g/I_d \sim 10^{-3} \div 10^{-2}$ where I_d is the drain current) does not contribute much to the output noise. On the other hand, in HFETs with a relatively small values of α ($\alpha \sim 10^{-5} \div 10^{-4}$), the contribution of the leakage current noise can be significant even at $I_g/I_d \sim 10^{-4} \div 10^{-3}$. For such transistors, a very rapid increase of the 1/f noise with gate bias has been observed. The reason for such a difference in the noise behavior can be explained by the difference in the structural quality of the AlGaN and GaN layers in different types of HFETs.

Figure 1 shows transfer current voltage characteristics of the HFETs and MOS-HFETs transistors fabricated on the same wafer under identical conditions. The dependencies of the absolute value of the gate leakage current I_g on gate voltage are also shown. Note that for the AlGaN/GaN HFETs, the I_g/I_d ratio is equal to 0.2 - 0.1 at $I_d = 10^{-4}$ A. For MOS-HFETs, at the same value of $I_d = 10^{-4}$ A this ratio is less than 10^{-6}.

Figure 2 shows the dependencies of the relative spectral noise density S_{Id}/I_d^2 on drain current for several HFETs and MOS-HFETs at constant drain voltage V_d=0.5V. It is seen that at high drain currents ($V_g = 0$), the values of S_{Id}/I_d^2 are practically equal for both types of transistors. The noise level corresponds to the Hooge parameter $a = (S_{Id}/I_d^2)Nf \approx 10^{-3}$ (N is the total number of carriers between drain and source). At $I_d \sim 10^{-4}$ A ($V_g \approx -4.5$ V for HFETs and $V_g \approx -9$ V for MOS-HFETs), the I_g/I_d ratio differs by more than 5 orders of magnitude for HFETs and MOS-HFETs. However difference in noise level S_{Id}/I_d^2 does not exceed a few decibels. Hence we conclude that gate leakage current does not contribute to noise.

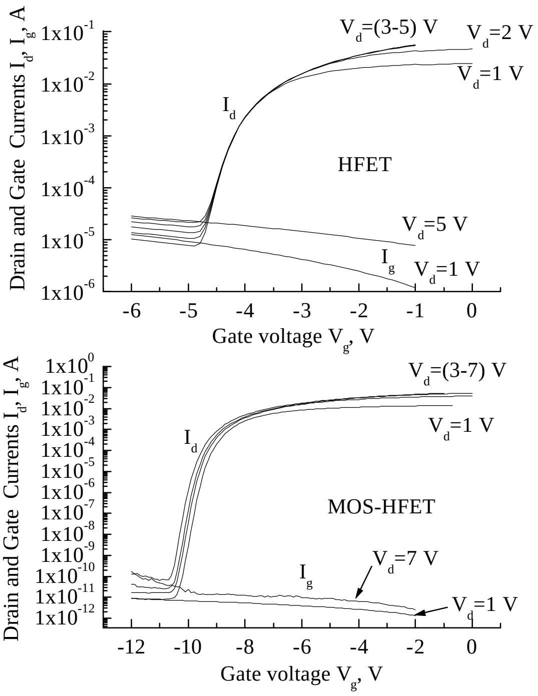

Fig.1 Transfer characteristics and gate leakage current in HFET s and MOS-HFETs.

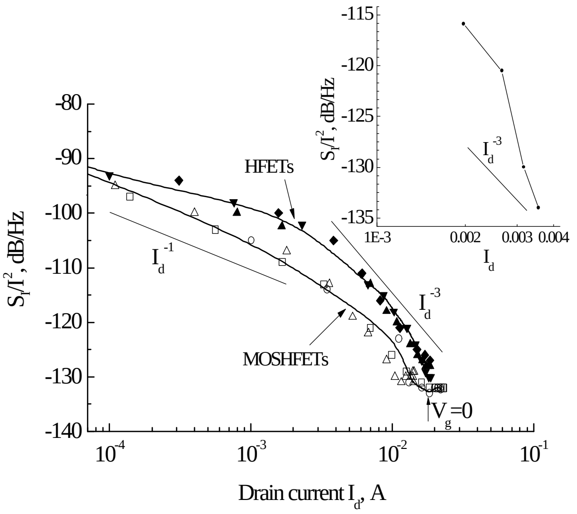

Fig. 2 Dependence of the relative spectral noise density of drain current fluctuations S_{Id}/I_d^2 on drain current at constant drain voltage V_d=0.5V. Frequency of analysis f=200 Hz. Inset shows the same dependence for the transistor with gate current contribution to the output noise.

This conclusion was supported by direct measurements of the gate current fluctuations and by the estimates of their contribution to the output noise.

On the other hand, the measurements of the gate current fluctuations in HFETs with α value of 10^{-4} showed that for such transistors, the gate current fluctuations makes the main contribution to the output noise even at $I_g/I_d \sim 10^{-4} \div 10^{-3}$. The inset in Fig.1 shows the dependence of the relative spectral noise density S_{Id}/I_d^2 on drain current at constant drain voltage V_d=0.5V for the transistor of that type.

These two different types of HFETs demonstrate qualitatively different dependencies of the correlation function on the value of external resistor R_g connected in series with the gate. For the HFETs with the characteristics shown in Figs. 1 and 2, correlation function is equal to zero at small values of R_g. The correlation function for the second type of HFETs (see inset in Fig.2) is relatively high even at very small values of R_g.

Acknowledgment M. E. Levinshtein gratefully acknowledges support of European Research Office of the US Army under Contract No 68171-99-M-6802

References

1. J. A. Garrido, F. Calle, E. Munoz, I. Izpura, J. L. Sanches-Rojas, R. Li, and K. L. Wang, *Electron. Lett.* **34**, 2357 (1998)
2. S. Rumyantsev, M. E. Levinshtein, R. Gaska, M. S. Shur, J. W. Jang, and M. A. Khan, *J. Appl. Phys*. **87,** 1849 (2000)
3. N. Pala. R. Gaska, S. Rumyantsev, M. S. Shur, M. Asif Khan, X. Hu, G. Simin, and J. Yang. *Electronics Letters*, **36**, 268 (2000)
4. L. K. J. Vandamme. D. Rigaud, and J.-M. Peransin, *IEEE Trans. on El. Dev.*, **39,** 2377 (1992)

5. G. B. Alers, K.S. Krish, D. Monroe, B. E. Weir, and A. M. Chang, *Appl. Phys. Lett.,* **69**,2885, (1996)