INFLUENCE OF THE GATE LEAKAGE CURRENT ON THE NOISE PERFORMANCE OF MESFETs AND MODFETs

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ABSTRACT:

In this paper, the influence of the gate leakage current on the noise performance of MESFETs and MODFETs is investigated. It is shown that the noise performance of FETs is strongly dependent on the gate leakage current value, especially at a few GHz. The theoretical results are discussed and are compared with experimental data.

INTRODUCTION

In order to obtain high microwave performance, the use of a short gate deposited on a thin highly doped layer is necessary for MESFETs and MODFETs realization. It is well known that the reverse leakage current of a Schottky barrier increases in the case of highly doped layers. Therefore, the gate leakage current (GLC) can be noticeable, especially in the case of AlInAs/GaInAs/InP MODFETs. The GLC introduces not only a parasitic conductance located at the device input, but also adds shot noise sources. The aim of this communication is to present a theoretical and experimental study of the influence of the GLC on the noise performance of Field Effect Devices.

THEORETICAL ANALYSIS

The GLC effect was introduced in the Software HELENA. HELENA is a physical FET modeling based on the quasi-2D approach [1] in which the microwave and noise performance is calculated using the active line method [2]. To calculate the macroscopic noise sources by the Impedance Field Method, a slice of the channel under the gate is described by a local small signal equivalent circuit including two microscopic noise sources (figure 1). The four parameters Δg_g - Δc_0 - g_m - Δr_0 of the local small signal equivalent circuit are deduced from the physical quantities (gate-to channel voltage, sheet carrier density, electrical field, average carrier velocity, average carrier energy...)[2]. The diffusion noise source $<i_n^2>$ is calculated from the sheet carrier density and the diffusivity while the local shot noise source $<i_{gn}^2>$ is simply $2.q.\Delta I_g$ where ΔI_g is the GLC flowing in the considered slice. Since the physical quantities vary under the gate, the six parameters g_g - Δc_0 - g_m - Δr_0 - $<i_n^2>$ - $<i_{gn}^2>$ of the noisy active line also vary and the line is basically non uniform.

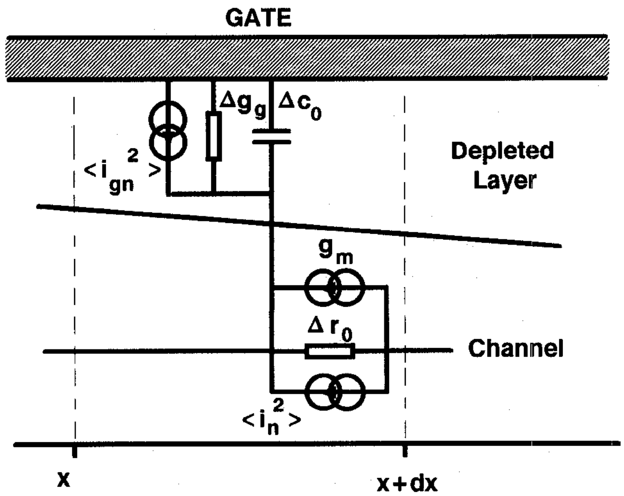

Figure 1 : The noisy local small-signal equivalent circuit.

The theoretical analysis shows that the microscopic shot noise sources distributed under the gate provide not only a macroscopic gate noise source $<i_{gsh}^2>$, but also a drain noise source $<i_{dsh}^2>$ correlated with $<i_{gsh}^2>$. It was found that the $<i_{gsh}^2>$ value is close to the classical expression $2.q.I_g$ while $<i_{dsh}^2>$ can be written $\alpha q I_g$ where the coefficient α varies from 0.5 to 1.5 according to the biasing conditions. The correlation coefficient between $<i_{gsh}^2>$ and $<i_{dsh}^2>$ is real and close to (-1). These results are in good agreement with those previously obtained by A. Van Der ZIEL in the case of junction FETs [3]. Therefore, a noisy FET showing GLC can be represented by a

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noiseless two-port associated together with two correlated diffusion noise sources and two correlated shot noise sources (Figure (2)).

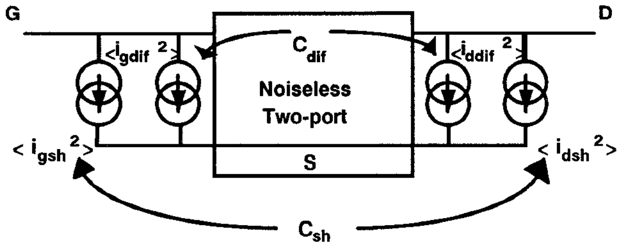


Figure 2 : Noisy small-signal equivalent circuit of MESFETs or MODFETs including shot noise sources.

Obviously, due to different physical origins, diffusion noise sources and shot noise sources are not correlated. As a consequence, the total gate and drain noise current sources and the cross correlation can be written:

$$<i_g^2> = <i_{gsh}^2> + <i_{gdif}^2>$$

$$<i_d^2> = <i_{dsh}^2> + <i_{ddif}^2>$$

$$<i_g.i_d^*> = <i_{gsh}.i_{dsh}^*> + <i_{gdif}.i_{ddif}^*>$$

Introducing the dimensionless coefficient P, R and C [4] and the values of the shot noise sources , we get :

$$<i_g^2> = (4.k.T_a.\Delta f.\omega^2.C_{gs}^2/g_m).R + 2.q.I_g$$

$$<i_d^2> = (4.k.T_a.\Delta f.g_m).P + \alpha.q.I_g$$

$$<i_g i_d^*> = j.C.4.k.T_a.\Delta f.\omega.C_{gs}.\sqrt{PR} - \sqrt{2\alpha}.q.I_g$$

In these expressions, I_g is the GLC value, k the Boltzmann constant, T_a the ambient temperature, Δf the frequency bandwidth, C_{gs} the gate capacitance and g_m the transconductance. These formula lead to the following remarks:

(i) The part of the gate noise current source $<i_{gdif}^2>$ resulting from diffusion noise vary as ω^2 while the part of the gate noise current source $<i_{gsh}^2>$ resulting from shot noise is frequency independent. Therefore, the shot noise significantly influences the gate noise $<i_g^2>$ for frequencies lower than the frequency f_{sh} providing $<i_{gdif}^2> = <i_{gsh}^2>$. f_{sh} is given by :

$$f_{sh} = \frac{g_m}{2.\pi.C_{gs}} \sqrt{\frac{q.I_g}{2.g_m.R.k.T_a.\Delta f}}$$

f_{sh} is obviously high for high GLC but also in the case of high performance device showing high cutoff frequency $g_m/2\pi C_{gs}$.

(ii) the influence of the GLC can be noticeable on the drain noise source near pinch-off when g_m is low.

(iii) the cross correlation between gate and drain noise sources is no longer imaginary when GLC is present.

RESULTS

In order to quantitatively specify the degradation of the FET noise performance as a function of the GLC magnitude, several modelings have been performed. The device investigated is a 0.4 x 100 μm^2 pseudomorphic MODFET. It is assumed that for $V_{ds}=0$ V, the GLC density J_g follows a cubic relation versus gate voltage.

$$J_g = \beta.(V_{gs})^3$$

Parameter β was chosen to give GLC densities varying from 4 10^3 A/m^2 to 4 10^6 A/m^2 at V_{gs} = - 2 V and V_{ds}=0 V.

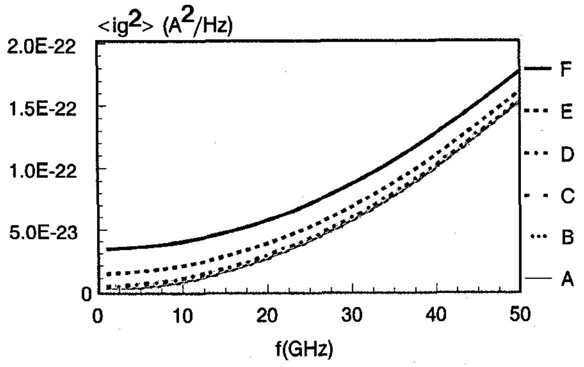
The actual GLC densities obtained in the device under low noise biasing conditions (I_d = 50 mA/mm ; V_{ds}= 2 V) are given in table I.

Case	A	B	C	D	E	F
GLC density at Vgs = - 2 V and Vds = 0 V.	0	4E3	4E4	4E5	1.5E6	4E6
Actual GLC density at Vds = 2 V	0	2.6E3	2.6E4	2.6E5	1E6	2.6E6

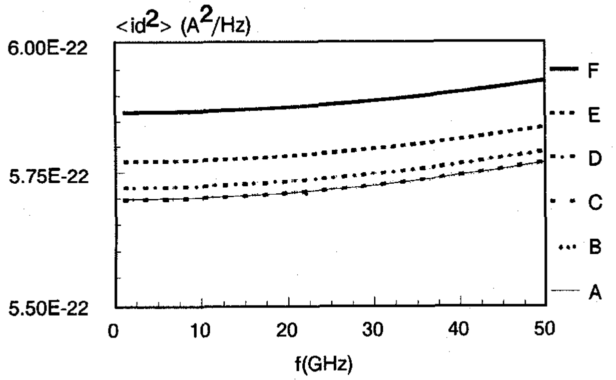
Table I

Figure (3a) to (3d) shows the variations of the gate and drain noise sources and the correlation coefficient as a function of the frequency. These figures show that the GLC has a strong effect not only on the gate noise current but also on the correlation coefficient. It can be noted that the imaginary part of the correlation strongly decreases for high GLC while the magnitude of the real part increases. These effects are more pronounced at low frequencies.

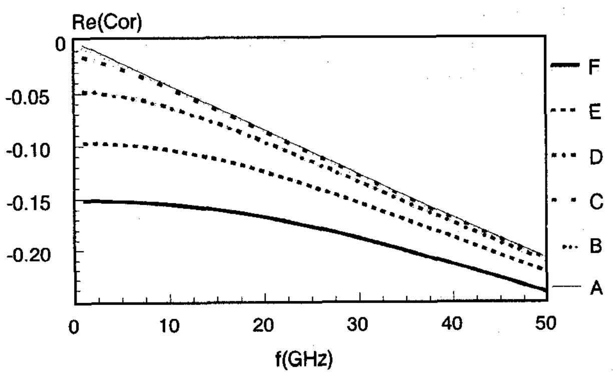
(a)



(b)



(c)



(d)

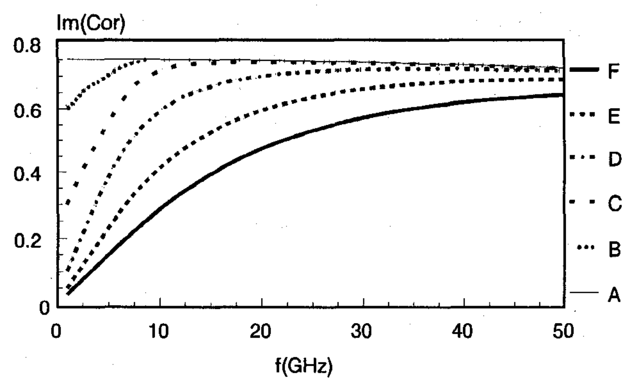


Figure 3 : Theoretical variation of $<i_g^2>$, $<i_d^2>$ and normalized correlation coefficient Cor versus frequency for several GLC values.

Figure (4) shows the minimum noise figure F_{min} versus frequency for the different values of the GLC density. the GLC strongly degrades the minimum noise figure, especially at low frequencies. This effect can be related to the variations of the noise sources and the correlation previously shown. Fortunately, this effect is strongly reduced for frequencies of operation larger than f_{sh}. As a consequence, the GLC effect is more important on the noise performance at a few GHz. However, the minimum noise figure increases, even in the millimeter wave range, in the case of very high GLC. In addition, Figure (4) shows that in the case of devices showing GLC, the frequency variation of the minimum noise figure versus frequency is strongly non linear at low frequencies. Therefore, the extrapolation of the minimum noise figure at high frequency from measurements performed at low frequency is questionable in this case.

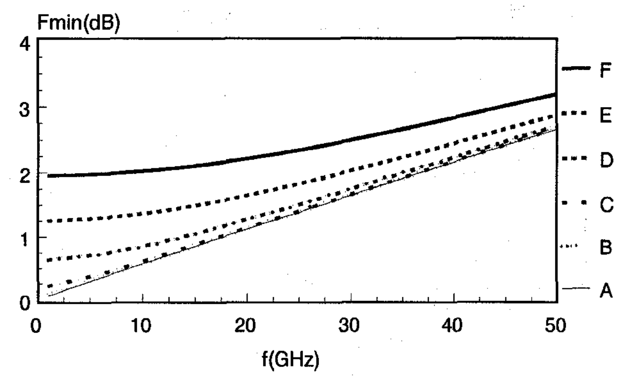


Figure 4 : Theoretical variations of F_{min} versus frequency for several GLC values.

Finally, Figure (5) shows the variation of F_{min} at 2 GHz as a function of the GLC density value (determined at Vds=0 and Vgs=-2V). It is clear that the GLC influence is very important at this frequency for GLC densities larger than 10^5 A/m^2. The use of ultra low GLC device is necessary for applications in this frequency range.

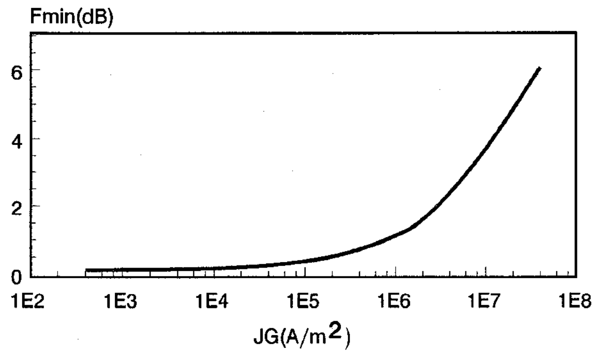


Figure 5 : Theoretical variation of F_{min} versus GLC density at 2 GHz.

EXPERIMENTAL RESULTS

In order to show the validity of this theoretical analysis, the experimental variation of the minimum noise figure as a function of the DC drain voltage is shown in Figure (6). For this specific device, F_{min} strongly increases at high drain voltage when GLC cannot be neglected while F_{min} is almost independent of the drain voltage for small GLC. It is also clear that the strong degradation of the minimum noise figure is related to the increase of the GLC.

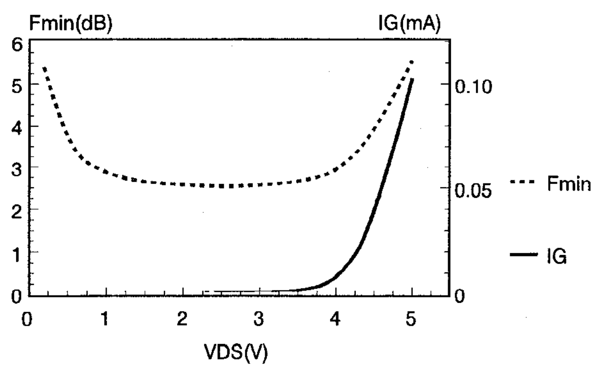


Figure 6: Experimental variation of F_{min} (at 12 GHz) and GLC versus drain voltage.

CONCLUSION

It has been shown that the GLC has a strong influence on the noise performance of FETs, especially at low frequency. This effect has to be taken into account for the CAD of ICs. For high GLC devices, the degradation of the noise performance can be observed even in the millimeter wave range.

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