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MOSFET 1/f NOISE MODELING

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ABSTRACT:
Simulation of Low Frequency Noise, LFN, in MOSFETs is known to account for the experimental data and a three-parameter BSIM model was found to be adequate for simulating the LFN data. However, a more physical approach, evoking the trapping – release phenomena on the dielectric/channel Si interface, requires that the power spectral density, PDS, should be proportional to g_m^2, where $g_m=\delta I_d/\delta V_g$ (transconductance). For small V_d (ohmic region) this trend was observed to break down at sufficiently high drain currents (high V_g), where the PSD function is seen continue to rise, preserving, in some cases, an almost quadratic I_d dependence, in spite of the simultaneous decrease in g_m (V_g).

INTRODUCTION

This paper is meant to contribute to the discussion on the mechanism of low frequency noise, LFN, generation in the region of gate voltages, V_g, where the channel current, I_d, enters the saturation regime [1]. In that region of I_d intensities the number fluctuation mechanism of LFN generation should become less efficient because of the decrease in the transconductance, $g_m=\delta I_d/\delta V_g$. However, the LFN continues to increase as for the lower I_d. These observations were first made when LFN data were simulated using some accepted models, such as SPICE, HSPICE and BSIM [1,2].

DISCUSSION

It is known that the trapping/release phenomena occurring at/or near the interface between the gate dielectric and the Si channel account for the LFN in a wide range of the drain current, I_d, intensities [3,4]. A single charge trapping de-trapping induces a flat-band potential fluctuation $\delta V_{fb}=-q/C_{ox}$, which, in turn, can be transformed into the drain current fluctuations $\delta I_d = (\delta I_d/\delta V_{fb})\,\delta V_{fb} = (g_m)\,\delta V_{fb}$. The sum of such elementary fluctuations, squared, gives the LF number-fluctuation noise (Δn), as demonstrated in the celebrated paper of McWhorter [3]. There is no reason to question the validity of that approach in the region of higher I_d intensities. However, the power spectral density of current fluctuations, S_{Id} is found to continue to rise also in the region where g_m decreases, with a somewhat diminished slope. This problem has been already evoked [1] but as yet found no satisfactory explanation.

As we use now an automatic PSD data-taking routine [5], we can measure S_{Id}(Vg) at V_g varied by small increments and we can thus produce families of LFN characteristics at any fixed frequency, f, with no major time investment. In Fig. 1 we compare a $I_d(V_g)$ and $\sqrt{}(S_{Id}(V_g))$ taken at 10 Hz, on a W/L=20/0.3µm, all Si pMOSFET at V_d=50mV (for device description cf. [6]).

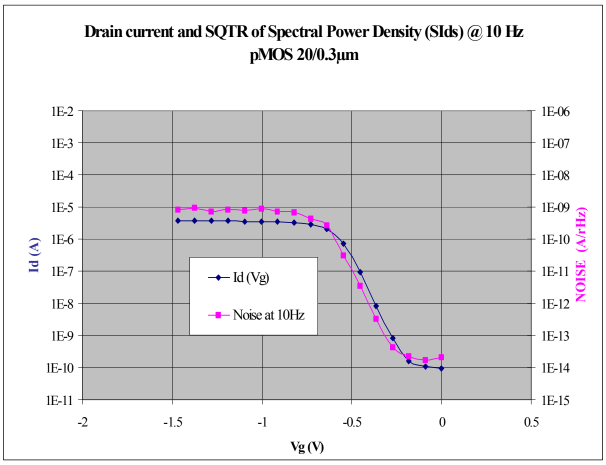

Fig. 1. Comparison of static and a noise characteristics, resp. $I_d(V_g)$ and $\sqrt{}(S_{Id}(V_g))$ @ at 10 Hz, taken on a W/L=10/0.3µm pMOSFET.

As is seen in Fig. 1, both functions follow the same trend, which means that S_{Id} is almost a quadratic function of I_d, even though the latter enters the saturation regime at the left hand side of the drawing, where g_m is significantly reduced. Such a near-perfect matching of the static and noise characteristics is not always found, however the absence of a decrease of LFN at the flattening of $I_d(V_g)$, (where g_m diminishes) seems to be general. It should be reminded here that this dependence is given in the HSPICE model. On the other hand a nearly quadratic I_d dependence in S_{Id} corresponds to the SPICE formulation, $S_{Id}(V_g)$=const* I_d^{AF}, with AF≈2. One should mention it here, for completeness, that a three-parameter BSIM model has been successfully used to fit the MOSFET data [2].

A possible mechanism capable of increasing the LFN at high V_g is that of correlated "number-mobility", Δn-$\Delta\mu$ noise [4], as the trapping-release at high V_g is so intense that it can significantly affect the carriers' mobility. However, Δn-$\Delta\mu$ cannot fully compensate the g_m diminution in the respective region of I_d intensities.

Another mechanism contributing to the LF noise generation is the noise generated in the access resistance, R_{acc}. It should be noted that in transistor structures the access resistance noise S_{acc} can also have a 1/f component, which can be mixed into other 1/f contributions. In the ohmic region, S_{acc} can be best visualized in normalized S_{Id}/I_d^2 data, as that contribution to the total current-normalized noise is equal to

$$S_{acc}/R_{acc}^2 = S_{acc}\ (I_d/V_d)^2\ . \qquad (1)$$

If that contribution is significant, the normalized data show an upward swing, with a quadratic current dependence in the high current regime. This often happens when the transistors are aged (large S_{acc}). In the data we present no such feature was observed, therefore the LFN generation in the access resistance has been disregarded. There have been some attempts [7, 8] to explain the increase of LFN beyond the Δn region, precisely by the presence of the access or "series resistance" between the source and drain terminals, with total resistance R_d. Recasting Eq. (1) in the $\Delta\mu$ -formalism, with a Hooge α_{acc} constant, we have

$$S_{Rsd}/R_d^2 = \alpha_{acc}\, q\mu'\, R_d/Xf, \qquad (2)$$

where μ' is the carrier mobility in the access resistance (made probably of Si) X is an effective length needed for obtaining the electric field E in the access resistance such that $E=V_d/X$. That mechanism should be strongly technology-dependent (through the parameters of the access resistance). However, as the access resistance is small in good-quality devices, the Hooge constant required may take too elevated values to be realistic. Nevertheless, this novel proposition of explaining the LFN increase at high currents merits a further study.

Finally, one should also mention the contribution of the thermal noise, $S_{th,}$ of the channel to the total noise. In the case of measurements involving a current amplifier the thermal noise contribution can be calculated [5] and it is given by the expression,

$$S_{th}=4kT(G_{AC})^2/R_{//}, \qquad (3)$$

where G_{AC} is the current amplifier's AC gain. The latter is equal to the resistance R_f in the feedback loop of the amplifier, if no additional amplification is provided in the AC channel of the current amplifier and $R_{//}=1/R_f+1/R_d$ with $1/R_d = (\delta I_d/\delta V_d) = I_d/V_d$ (in the linear regime). For the data presented in Fig. 1, the amplitude of S_{th} was found to be about 6 times lower than the amplitude of the total measured noise. It should also be mentioned that at 10Hz the noise still showed a distinct 1/f character, implying that the thermal noise contribution was small. However, at f>500Hz the white noise contribution to the total noise was perceptible at the G_{AC} values used in the pertinent current measurement range. The thermal noise contribution is mentioned here in order to show how important the instrumental factors could be for a correct data interpretation and analysis.

The problem of the origin of the LFN generation in the I_d saturation regime is important not only for modeling, but also because it presents an interesting problem in device physics. Clearly more work is required to elucidate its origin.

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