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Drastic reduction of the low frequency noise in Si(100) p-MOSFETs

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1. Introduction

The low frequency noise commonly called 1/f noise or even Flicker noise has always been a limiting factor for analog and digital circuits. Its undesirable impact is even visible in radio frequency devices. Since the input signal needs to be maintained high enough in order to keep a signal/noise ratio acceptable, the reduction or even the hypothetical eradication of the low frequency noise would make the electronic world enter into a new era of ultralow power consumption devices handling very small signals.

On the account of new fabrication processes, we demonstrate in this paper that very efficient ways for reducing the 1/f noise in MOSFETs have been achieved. Moreover, a drop down to almost 4 decades can be expected regarding the Si(100) p-MOSFETs.

2. 1/f noise

In the MOSFETs, the 1/f noise is actually stemming from 2 distinctive regions. The first contribution, that is very often omitted even if its impact is tremendously important, is coming from the access resistances R_{acc} while the second one is coming from the channel.

The 1/f noise S_{Id} is thus the sum of both contributions and can be written as

$$\frac{S_{I_d}}{I_d^2} = \left(\frac{S_{I_d}}{I_d^2}\right)_{channel} + \left(\frac{I_d}{V_d}\right)^2 S_{R_{acc}} \qquad (1)$$

where I_d is the drain current, V_d the drain voltage and S_{Racc} the noise generated by R_{acc}. Concerning the noise stemming from the channel, it is now well accepted that the capture and release of carriers into slow oxide traps nearby the Si/SiO_2 interface actually leads to fluctuations of the insulator charge ΔQ_i. The surface potential is consequently deformed and is then inducing mobility fluctuations $\Delta\mu_{eff}$. The normalized noise is expressed in the linear regime by [1]

$$\frac{S_{I_d}}{I_d^2} = \Delta Q_i + \Delta\mu_{eff} = \left(1 + \alpha\mu_{eff} C_{ox}\frac{I_d}{g_m}\right)^2 \frac{g_m^2}{I_d^2} S_{V_{fb}} \quad (2)$$

where g_m is the transconductance, C_{ox} the oxide capacitance, μ_{eff} the effective mobility and S_{Vfb} the spectral density of the flat-band voltage. ΔQ_i and $\Delta\mu_{eff}$ are related together by the Coulomb scattering coefficient α that reflects the strength between both quantities. The total 1/f noise in a MOSFET is eventually the sum of all quantities like depicted in the synopsis of Fig. 1.

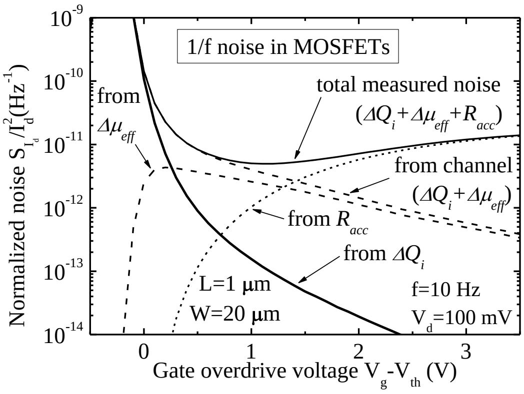

Fig. 1: Synopsis of the low frequency noise in a MOSFET and of its several contributions.

3. Experiment and results

For a given drain voltage, the noise S_{Id} is measured in function of the frequency at different gate biases like shown in Fig. 2. The noise at 10 Hz is thus collected, analyzed and finally modeled with the help of Eq. 1 and 2.

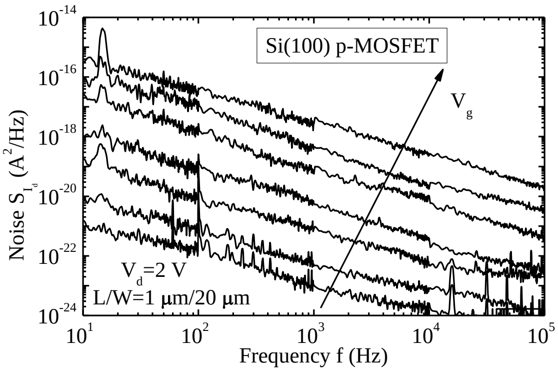

Fig. 2: 1/f Noise spectral density of the drain current in a MOSFET in function of the frequency for several gate voltages.

Two types of Si(100) n-MOSFETs have been fabricated in our super clean room at NICHe, Tohoku University. While the first one featured conventional source and drain contacts, the second one has been fabricated with erbium silicide contacts and thus resulted in a more than 10 times drop of R_{acc} [2]. The low frequency noise has been then studied and the results have been plotted in Fig. 3.

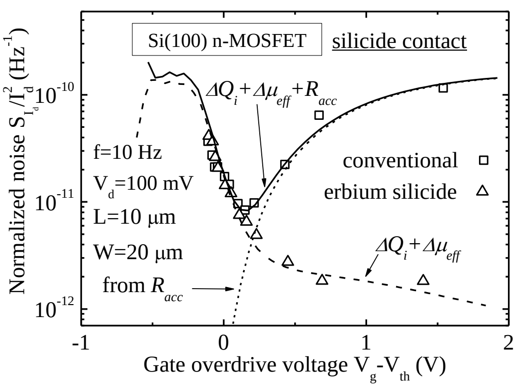

Fig. 3: Noise and their respective model versus V_g-V_{th} in Si(100) n-MOSFETs with conventional (square symbol) and erbium silicide (triangle symbol) contacts.

While both noise levels are similar at low V_g-V_{th}, they split around 0.2 V. The contribution of R_{acc} to the 1/f noise has been reduced so that the 1/f noise for the device featuring erbium silicide contacts has been modeled exclusively with Eq. 2. Thus, the 1/f noise is uniquely stemming from the channel. The use of the erbium silicide for the fabrication of the source and drain contacts, not only enhances the drivability but drastically reduces the noise in the MOSFET.

Looking at the noise studies carried out on Si(100) p-MOSFETs in the literature and to the best of our knowledge, the 1/f noise originating from the channel is always caused by both fluctuations of the insulator charge and of the induced mobility with a Coulomb scattering coefficient α found in most cases around 10^5 Vs/C [3].

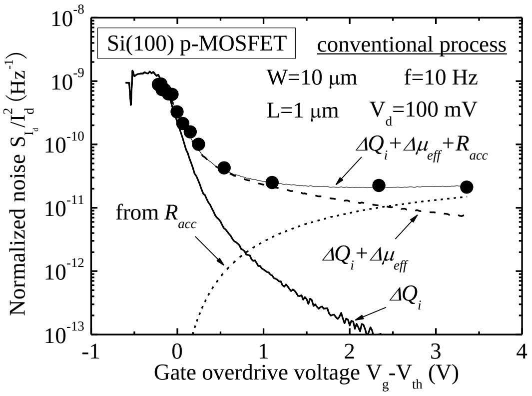

Fig. 4: Noise and its model versus V_g-V_{th} in conventional Si(100) p-MOSFETs. The contacts are conventional ones.

Indeed, a short study carried out on conventional devices and summarized in Fig. 4 confirmed that trend. $\Delta\mu_{eff}$ has a non negligible contribution to the 1/f noise. However, on account of a noise study carried out on a Si(100) p-MOSFET fabricated at NICHe and involving newly developed processes [4], we noticed a peculiar noise behavior. Contrary to what was expected, the induced mobility fluctuations $\Delta\mu_{eff}$ were not visible and thus the fluctuations of the insulator charge ΔQ_i alone were responsible for the 1/f noise ascribed to the channel. This observation, which has been reported in Fig. 5, has been strengthened by further studies on other samples, all coming out of our clean room.

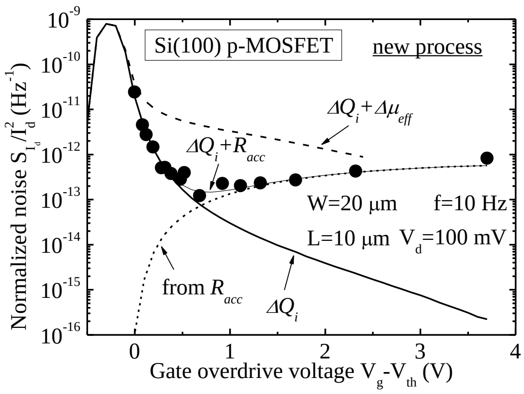

Fig. 5: Noise and its model versus V_g-V_{th} in Si(100) p-MOSFETs fabricated at NICHe. The contacts are conventional ones.

Finally, we have to emphasize that the contacts of the device presented in Fig. 5 are conventional ones and their contribution to the total 1/f noise is consequently visible. Like we addressed in Fig. 3, the optimization of these contacts (use of palladium silicide for the p-MOSFETs) [5] will make the 1/f noise stemming from R_{acc} drastically drop and bring the 1/f noise in our Si(100) p-MOSFET at an almost 4 decades lower level which corresponds to the fluctuations of the insulator charge ΔQ_i alone.

3. Conclusion

A first drastic reduction of the 1/f noise in the MOSFETs has been achieved by the reduction and thus the optimization of the source and drain contacts. In addition, a second reduction in the case of the Si(100) p-MOSFETs has been achieved by the use of new processes leading to the weakening of the induced mobility fluctuations $\Delta\mu_{eff}$ to finally make the fluctuations of the insulator charge ΔQ_i the unique noise source of the 1/f fluctuations. By the means of these new technologies, the power consumption of electronic devices can be drastically reduced. Moreover, the size of the electronic circuits and especially the analog and RF ones can be greatly scaled down.

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