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On the Variability and Front-Back Coupling of the Low-frequency Noise in UTBOX SOI nMOSFETs

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Abstract

A low-frequency (LF) noise characterization of UTBOX SOI nMOSFETs is undertaken in order to understand the variation of the electron mobility in the front-channel. It is shown that there exists a reasonable correlation between the two parameters, which can be explained by Coulomb scattering at charged traps in the front and back-gate oxide. Exceptions to the observed trend are related to the presence of excess Generation-Recombination (GR) noise, associated with deep levels in the thin Si film.

1. Introduction

One way to mitigate the impact of Random Dopant Fluctuations (RDFs) on CMOS device variability [1] is by switching over to a fully depleted (FD) intrinsic channel Silicon-on-Insulator (SOI) architecture [2]. At the same time, this allows a good control over the Short Channel Effects (SCEs) for a silicon film thickness on the order of a quarter of the effective gate length ($L/4$). In case an ultra-thin Buried Oxide (UTBOX) is implemented, the ground-plane or substrate doping can be further fine-tuned for threshold voltage (V_T) control [2]. However, there exist other sources of variability, associated with randomly distributed trapped charge in the gate oxide, which can yield a device-to-device variation of the static performance parameters [1,3]. In fact, it is already known for quite some time that this gives rise to significant dispersion in the low-frequency noise Power Spectral Density (PSD) of small-area transistors [4-6].

It is the aim of the present work to investigate the variation of the noise PSD of UTBOX SOI nMOSFETs across the diameter of the wafer and to compare it with the corresponding V_T and low-field electron mobility μ_n in linear operation. It is demonstrated that there is a reasonable correlation between the front PSD and μ_n for most of the devices, which can be explained by the fact that the $1/f$-like noise is governed by oxide trapping, which at the same time cause a Coulomb scattering of the electrons. Outliers will be discussed in terms of excess Generation-Recombination (GR) noise and of the possible impact of traps in the BOX, through front-back coupling in thin-film devices [7].

2. Experimental details

The 1 μmx69 nm nMOSFETs (channel width x channel length) under study have been fabricated on 300 mm diameter UTBOX SOI wafers, with a BOX thickness of ~18 nm and a film thickness of ~14 nm (values after device processing). A 5 nm thermal oxide has been grown, which was covered by 10 nm TiN and a polysilicon cap. The devices have no extensions, which improves the retention time of the one-transistor Floating-Body RAM memory operation [8]. The transistors were fabricated with a ground-plane implantation to suppress field penetration through the thin BOX.

Low-frequency noise has been measured at room temperature and in linear operation (drain voltage V_{DS}=50 mV), with the front (V_{GS}) or back gate voltage (V_{GB}) stepped from weak to strong inversion. The front-channel noise was measured with V_{GB}=0 V and vice versa. The threshold voltage and μ_n have been extracted from the input I_D-V_{GS} characteristics in linear operation using the Y-function method [9].

3. Results

As shown in Figs 1 and 2, the DC parameters exhibit a significant scatter across the vertical diameter of the wafer. However, this is much less than the corresponding spread in the input-referred voltage noise PSD at 25 Hz and flat-band (S_{VFB}), represented in Fig. 3 and in line with what is expected for small-area transistors [4-6]. The variation amounts to nearly two decades as better shown in Fig. 4.

At the same time, according to Fig. 4 there appears to be a trend between the noise PSD and μ_n, with higher mobility corresponding with a lower PSD. This tendency has been observed in the past for other types of MOSFETs as well [10-12].

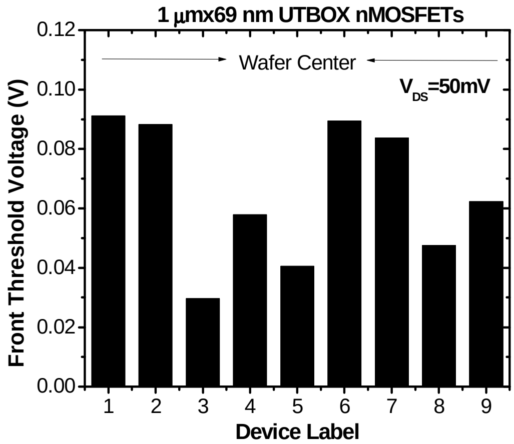

Figure 1. Front-gate threshold voltage at V_{GB}=0 V and V_{DS}=50 mV for a set of 1 µmx69 nm UTBOX nMOSFETs along the vertical wafer diameter.

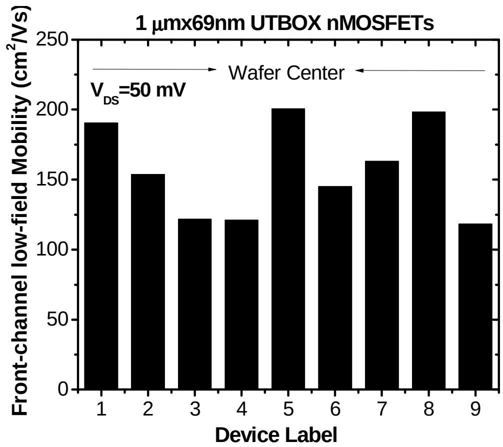

Figure 2. Front-gate low-field electron mobility at V_{GB}=0 V and V_{DS}=50 mV for a set of 1 µmx69 nm UTBOX nMOSFETs along the vertical wafer diameter.

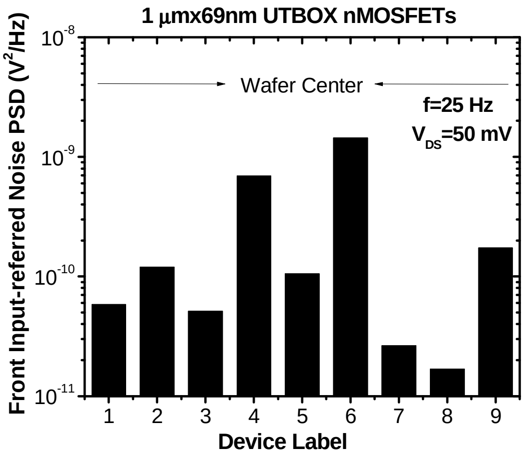

Figure 3. Front-gate input-referred noise PSD at V_{GB}=0 V and V_{DS}=50 mV for a set of 1 µmx69 nm UTBOX nMOSFETs along the vertical wafer diameter. The frequency f=25 Hz.

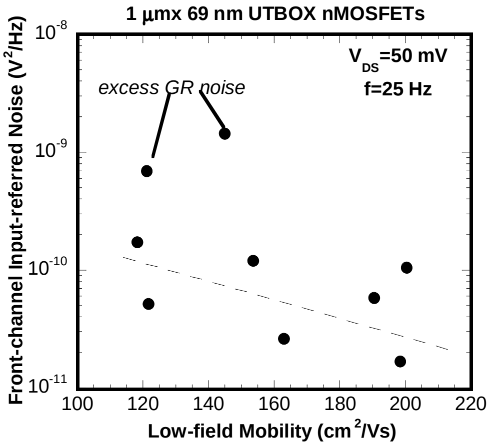

Figure 4. Front-gate input-referred noise PSD at V_{GB}=0 V and V_{DS}=50 mV versus low-field mobility for a set of 1 µmx69 nm UTBOX nMOSFETs along the vertical wafer diameter. The frequency f=25 Hz.

4. Discussion

As indicated in Fig. 4, some devices exhibit significantly higher noise than expected from the trend, which is ascribed to the occurrence of excess GR noise, caused by deep levels in the Si-film, giving rise to a pronounced Lorentzian in the spectra of Fig. 5a. On the other hand, most of the other transistors show predominantly 1/*f*-like noise at low frequencies (Fig. 5b). In order to gain further insight, the LF noise has also been measured in the back-channel (Fig. 5). According to Fig. 6, there exists a good correlation between the front- and the back-channel PSD. A linear fit to the data of Fig. 6, yields a slope of 9.8 which is close to the ratio $(t_{oxb}/t_{oxf})^2=(18/5)^2=12.96$ expected for 1/*f* noise governed by trapping in the gate oxide, provided that the trap density is the same in both front and back-gate oxide [7]. This implies that an oxide trap density N_{ot} can be extracted from the voltage noise PSD at flat-band condition, using [4,5]:

$$S_{VFB} = \frac{q^2 kTN_{ot}}{WLfC_{ox}^2 \alpha} \quad (1)$$

with q the elementary charge, kT the thermal voltage, f the frequency (25 Hz) and C_{ox} the oxide capacitance per unit of area. The average value for the front oxide yields $N_{otf}=1\times10^{17}$ cm^{-3}eV^{-1} and ranging from 2×10^{16} cm^{-3}eV^{-1} to 2×10^{17} cm^{-3}eV^{-1}. At the same time, we obtain for the BOX an $N_{otb}=6.5\times10^{16}$ cm^{-3}eV^{-1}, ranging from 2.2×10^{16} cm^{-3}eV^{-1} to 1.6×10^{17} cm^{-3} eV^{-1}. The slightly better values for the BOX can be accounted for by considering the

front-back noise coupling factor [7].
The variation of the front-channel electron mobility with front-channel noise of Fig. 4 can then be explained by considering Coulombic scattering at the charged oxide traps according to $1/\mu_{sc} \sim \alpha_{sc} q D_{ot}$, with D_{ot} in cm^{-2}. Considering an energy interval of 4kT (~0.1 eV) and a tunneling depth of ~2 nm yields a scattering parameter $\alpha_{sc} q \sim 2.9 \times 10^{-12}$ cm^2.

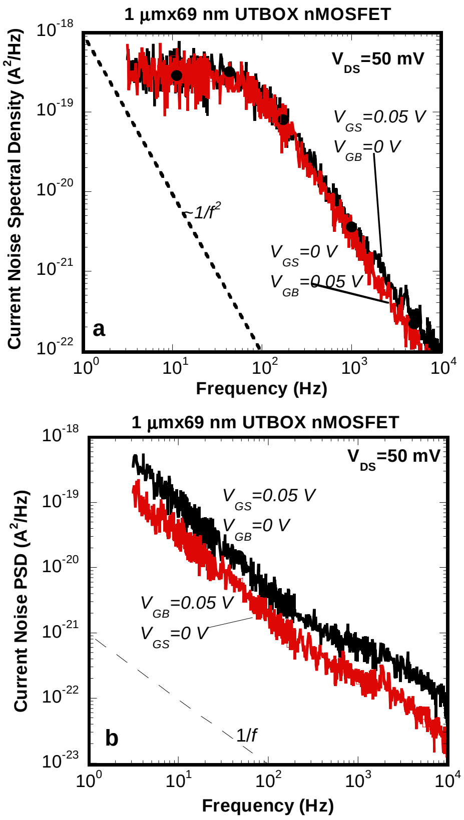

Figure 5. Current noise PSD for the front (black) and back-channel (red) in linear operation for a 1 µmx69 nm UTBOX nMOSFET showing excess GR noise (a) or predominantly flicker noise (b).

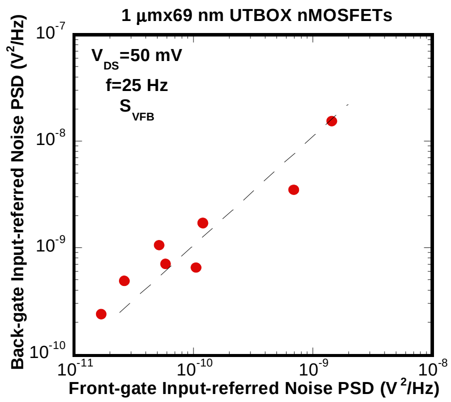

Figure 6. Back versus front channel average input-referred voltage noise power spectral density at flatband, f=25 Hz and linear operation (V_{DS}=50 mV) for a number of 1 µmx69 nm UTBOX nMOSFETs.

5. Summary

A reasonable correlation between the front-channel LF noise PSD and the front-channel electron mobility has been observed for a set of UTBOX SOI nMOSFETs, which can be explained by considering Coulombic scattering at charged front and back-gate oxide traps.

Acknowledgments

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