Low-Frequency Noise Analysis of the Asymmetric Self-Cascode Structure Composed by FD SOI nMOSFETs

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1. Abstract

In this work, the low-frequency noise in linear regime is experimentally assessed for the Asymmetric Self-Cascode structure composed by Fully Depleted SOI nMOSFETs concerning to the variation of the gate voltage and the channel doping concentration.

2. Introduction

The Asymmetric Self-Cascode (A-SC) is a structure proposed aiming to improve the analog characteristics of the well-known configuration formed by two transistors associated in series with short-circuited gates, operating as a single device [1]. The peculiarity of the A-SC structure is linked to the presence of two transistors with threshold voltage (V_{TH}) gap between them. As shown in Fig. 1, the transistor near the source (M_S) presents larger channel doping concentration in comparison with the transistor near the drain (M_D) [2]. In Fig. 1, L_S and L_D are the channel lengths of the M_S and M_D transistors, respectively. The total channel length is equal to L_S + L_D, but the effective channel length (L_{eff}) tends to L_S when the A-SC structure is biased around V_{TH}. The A-SC structure has exhibited several improvements on the analog performance compared with single transistors (STs) as well the traditional self-cascode configuration [2].

An important parameter for analog applications is the Low-Frequency Noise (LFN), which sets the limit of the minimum signal that can be inputted in analog circuits, impacting in the signal to noise ratio. In addition, the LFN is a tool to assess the quality of the $Si\text{-}SiO_2$ interface since the drain current (I_D) is confined to a narrow superficial channel under the gate oxide, being susceptible to traps at the $Si\text{-}SiO_2$ interface, in the gate oxide and in the silicon depletion layer [3]. The LFN is usually dominated by $1/f^{\gamma}$ noise (where f is the frequency) linked to fluctuations in the number of carriers [4] or in the mobility [5]. The oscillations cause

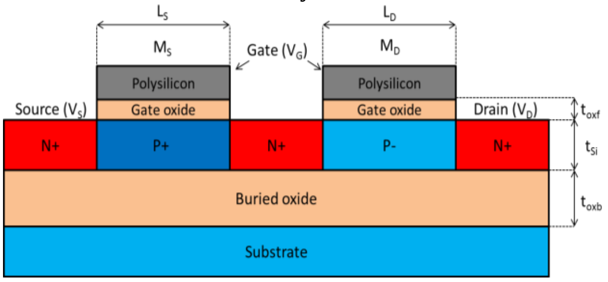

Fig.1. *Schematic cross-section of the Asymmetric Self-Cascode structure composed by FD SOI nMOSFETs.*

a variation in I_D. The "γ" range is from 0.7 to 1.3. If γ=1 the trap density is uniform in the gate oxide depth, if γ>1 the trap density is higher in the gate oxide and if γ<1 the trap density is larger close to the $Si\text{-}SiO_2$ interface. Another noise source is the generation-recombination noise, which is related to the capture and emission of carriers between the channel and the traps, with a Lorentzian spectrum (plateau followed by $1/f^2$ roll-off) [3]. This paper intends to analyze the origin of the LFN in the A-SC structure by comparing with STs.

3. Devices Characteristics

In this paper, transistors fabricated in a 150nm Fully Depleted (FD) SOI technology from OKI Semiconductors have been measured in linear regime. STs present channel length of 150nm and channel width (W) of 10µm. The gate oxide (t_{oxf}), silicon film (t_{Si}), and buried oxide (t_{oxb}) thicknesses are 2.5, 40 and 145nm, respectively. The channel doping concentrations have been varied, leading to threshold voltages of 0.02, 0.33 and 0.57V. By associating the transistors in series, the A-SC structures have been formed, maintaining the transistor with larger V_{TH} close to the source.

4. Results

Firstly, the DC input characteristics are evaluated in Fig. 2, where I_D (A) and the transconductance (g_m) (B) are plotted against the gate voltage overdrive ($V_{GT}=V_{GS}-V_{TH}$) for STs and A-SC structures with different channel doping concentrations. The drain current and g_m are affected by the increase of the channel doping concentration, since it reduces the mobility, as observed for STs. In the case of the A-SC structures, L_{eff} tends to L_S, however, due to the presence of the M_D transistor, there is a reduction of I_D and g_m linked to the increment of the resistance for the current flow. At high V_{GT}, L_{eff} tends to L_S + L_D, and g_m of the A-SC structures tends to half g_m of STs. Fig. 3 presents the drain current noise spectral density (S_{Id}) normalized by I_D^2 as a function of the frequency for the A-SC ($V_{TH,S}$=0.57V, $V_{TH,D}$=0.02V) structure. One can notice that the A-SC structures exhibit $1/f^{\gamma}$ and $1/f^2$ noise components. At $V_{GT}\geq0V$, only $1/f^{\gamma}$ noise is verified with γ=1, indicating that the trap density is uniformly distributed in the gate oxide depth. The presence of Lorentzians is noted at V_{GT}=-100mV due to the $1/f^2$ noise. When the A-SC structure is biased closer to the subthreshold regime, S_{Id}/I_D^2 increments, which is linked to the reduced free carrier concentration in the channel.

In this case, the carrier capture or emission by traps is more effective in generating fluctuations in I_D. As a way to determine the origin of the LFN of the A-SC structures, Fig. 4 shows S_{Id}/I_D^2 and $(g_m/I_D)^2$ as a function of I_D at f=45Hz. According to [6], if S_{Id}/I_D^2 is parallel to $(g_m/I_D)^2$, the noise source is related to carrier number fluctuations, whereas other trends indicate an influence of the mobility fluctuations on the noise. It is possible to see a good parallelism between S_{Id}/I_D^2 and $(g_m/I_D)^2$, which means that the carrier number fluctuations are the main type of noise source. Fig. 5 presents S_{Id}/I_D^2 as a function of the frequency for STs and A-SC structures at V_{GT}=0V. As seen in Fig. 3, only 1/f noise is noted for

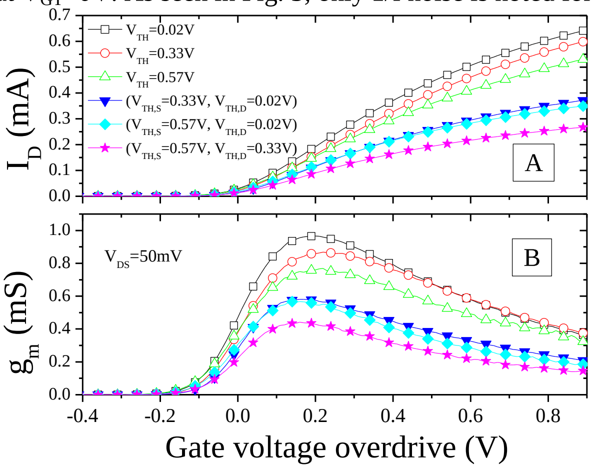

Fig.2. *I_D (A) and g_m (B) against V_{GT} for isolated devices (open symbols) and A-SC structures (closed symbols) at V_{DS}=50mV.*

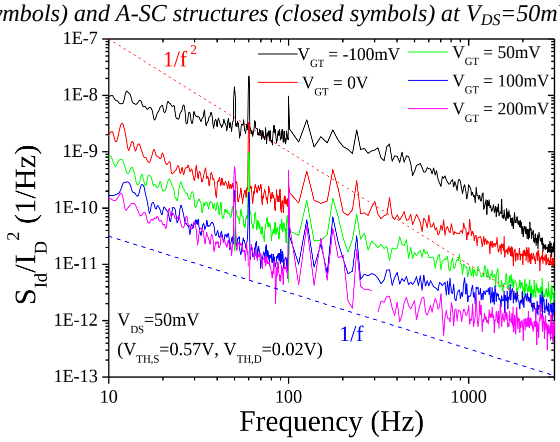

Fig.3. *S_{Id}/I_D^2 as a function of the frequency varying V_{GT}.*

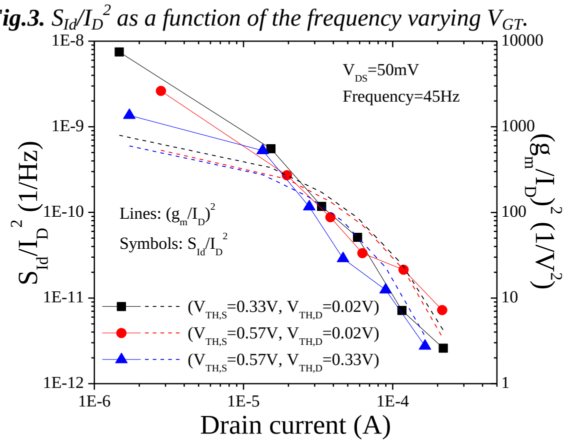

Fig.4. *$S_{Id}/I_D^2$and $(g_m/I_D)^2$ as a function of I_D at f=45Hz.*

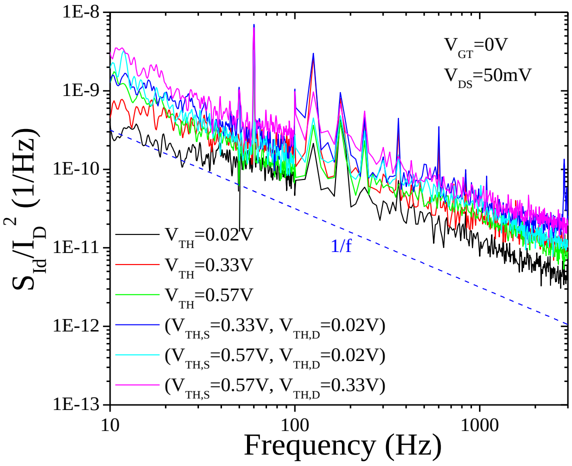

Fig.5. *S_{Id}/I_D^2 against frequency for STs and A-SC structures.*

all devices when V_{GT}=0V. Also, the increase of the channel doping concentration in STs increments the normalized noise, which is linked to the larger dose of ionic implantation, degrading the quality of the silicon interface and the gate oxide, and consequently, creating more traps. In the case of the A-SC structures, there are two transistors in series association, implying in the double of the gate area compared with single transistors, incrementing the number of oxide and interface traps, and also the normalized noise. Besides that, if the A-SC structure is formed by noisier devices, larger the noise will be. This way, the highest normalized noise has been observed for the A-SC ($V_{TH,S}$=0.57V, $V_{TH,D}$=0.33V) structure, since these single devices show larger noise due to the heavier channel doping concentration.

5. Conclusions

The low-frequency noise of the A-SC structures has been characterized by the presence of 1/f and $1/f^2$ noise components. It has been proved that the origin of noise source is linked to the carrier number fluctuations. The reduction of the gate voltage overdrive and the increase of the channel doping concentration have increased the normalized noise due to, respectively, the reduced amount of carriers in the channel and the larger dose of ionic implantation, which generates more traps at the silicon interface and in the gate oxide. The A-SC structures have exhibited higher noise compared with single transistors due to the larger gate area, incrementing the amount of oxide and interface traps.

Acknowledgments

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