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Low Frequency Noise and Mobility Correlation from RT to Low Temperatures for n-Channel Ge MOSFETs

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Abstract

This work demonstrate the correlation of low frequency noise (LFN) parameter, gate voltage overdrive index (*β*), with the mobility of Ge n-MOSFETs having decoupled plasma nitrided GeON as an interfacial layer. The correlation was studied from RT to cryo temperatures (150K) for low field and high field regimes separately, to understand the physical mechanism responsible for the noise. The study reveals a clear correlation between them and also indicates that, as opposed to Si, high field noise in Ge is dominated by number fluctuation, likely due to higher interface trap density close to the conduction band edge and low conduction band offset at Ge/GeON interface leading to enhanced carrier trapping/detrapping due to tunneling. The correlation is further reinforced when compared to Ge n-MOSFETs with GeO_2 as an interfacial layer having lower interface trap density.

1. Introduction

Germanium (Ge) has 2x times higher electron and 4x times higher hole mobility than Silicon (Si) and is also part of Si foundry from the last many technology nodes [1]. The recent advance in Ge interfacial layer and high-k technology makes Ge as a suitable candidate for the future channel material [2]. High mobility (μ) of n-channel Ge MOSFET is more challenging to realize, due to higher interface trap density (D_{it}) close to the conduction band edge (E_c) than close to the valance band edge (E_v) [3]. In our previous work, we have made an attempt to resolve this issue by using Decoupled plasma nitrided (DPN) GeON as an interfacial layer for Ge n-MOSFETs [2]. In order to make highly reliable and better gate stacks, we need to characterize the trap distribution and its effect on the device performance. Low frequency noise (LFN) (also called as a flicker noise) is a powerful tool to see the effect of spatial distribution of traps. And when the LFN measurements are performed at low temperatures, we can see the effect of traps close to the E_c as well. The μ is also an important device parameter which gets affected by the Coulombic centers (traps) close to the interface and hence studying mobility at low temperatures can also gives us the effect of traps close to the conduction band edge.

In this work, we have characterized the GeON gate stack using LFN and μ measurements from RT to low temperatures (150K). The study is divided into low field (Coulombic dominated) and high field (surface roughness dominated) regimes separately. The correlation between LFN parameter gate overdrive (V_{GS}-V_T) index (β) with low temperature μ is presented with the physical insight is also discussed briefly. The study is further extended and compared to Ge n-MOSFETs with GeO_2 as an interfacial layer having lower D_{it}.

2. Experimental details

The samples were fabricated using gate last process flow with DPN GeON and GeO_2 as an interfacial layer [2]. The LFN measurements were performed out using low noise current preamplifier and FFT spectrum analyzer. In order to avoid stress effects and gate pad degradation with multiple probing, low field and high field measurements were carried out on two different devices from the same sample.

3. Results and Discussions

Fig. 1 shows the drain current LFN ($A.\ S_{id}/I_D^2$) measured for the different gate voltages. As expected, at higher gate voltages the noise decreases because of screen out effect [4]. The β was calculated from the noise vs. gate overdrive (V_{GS}-V_T) at 10Hz as shown in the Fig. 1 inset.

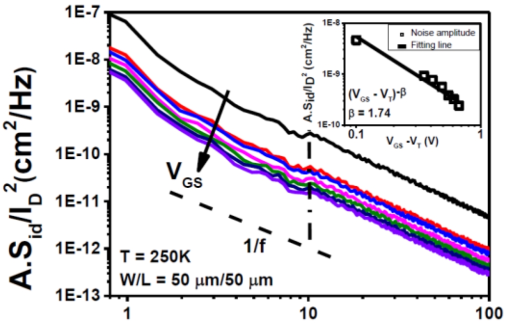


Fig. 1 Drain current LFN ($A.\ S_{id}/I_D^2$) at different gate biases. The inset shows the extraction of β at 10Hz.

The μ (Fig. 2(a) and (b)) was extracted using split CV technique. It can be seen that as opposite to Si, in case of Ge the μ decreases as the temperature decreases [5]. This clearly indicates that in case of Ge MOSFETs at lower temperatures due to large number of traps close to the E_c, Coulombic scattering mobility dominates and decreases overall mobility of the device.

The Fig. 3 (a) shows the correlation of μ and β for two regimes at different temperatures. The β value close to 1 indicates the mobility fluctuation as per the Hooge's model [6] and close to 2 indicates the number fluctuation as per the McWorther model [7]. As can be seen that for low field regime (N_s = 2e11 cm^{-2} to 9e11 cm^{-2}) from RT to 150K, the μ and β values follows the opposite trend. The reason for the trend can be explained as follows [8].

$$\Delta I_D/I_D = \Delta\mu/\mu + \Delta Q/Q \qquad (1)$$

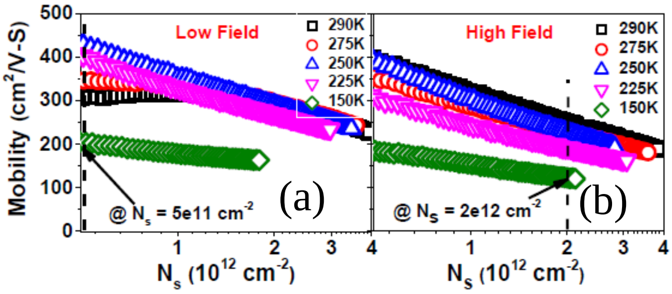
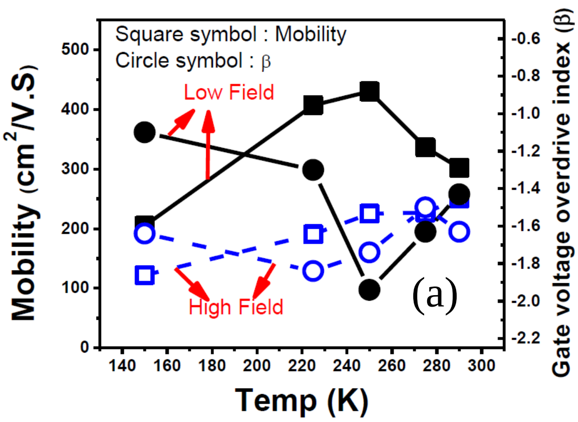
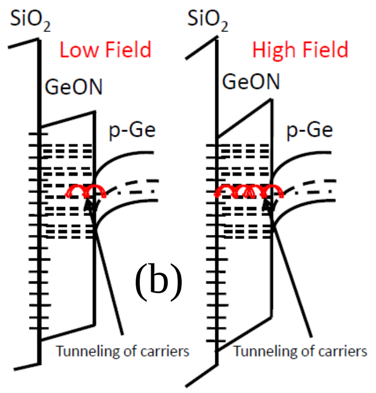


Fig. 2 (a) and (b) shows the mobility measured for low and high field devices from RT to 150K respectively.

The equation indicates that, mobility fluctuation ($\Delta\mu$) can dominates the drain current noise (ΔI_D), in case of lower μ values and/or at higher sheet charges (Q). For high field regime (N_s = 9e11 cm^{-2} to 3e12 cm^{-2}), the μ and β follows the same trend and β values are close to 2 (number fluctuations), which is contradicting to the above equation and opposite to Si [8,9]. At higher field, carriers can tunnel deeper inside the oxide likely due to lower conduction band offset at Ge/GeON interface (as shown in Fig. 3(b)) and hence can access larger number of traps leading to β close to 2. The reason for decreasing of β values with lowering of temperature can be explained by the fact that at lower temperature with high field the carriers can access the traps which are close to the E_c.

In order to compare the effect of different D_{it} on correlation, the study was extended and compared to Ge n-MOSFETs with GeO_2 as an interfacial layer at RT. Fig. 3 (c) shows that GeO_2 being better interface with lower trap density [2] leads to higher μ for Ge n-MOSFETs. As the μ value increases, the β values further shifts close to 2 (number fluctuation) as explained by equation 1. Hence, correlation of μ and LFN is valid for Ge n-MOSFETs with different interfacial layer.





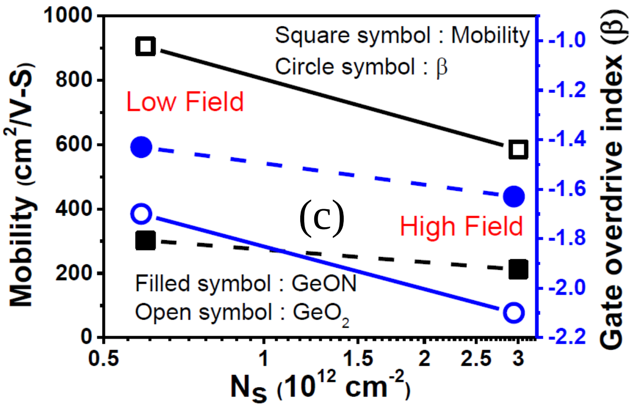


Fig. 3 (a) shows the correlation of μ and β at low field and high field for different temperatures, (b) band diagram schematic showing different tunneling probability at low field and high field seperately and (c) shows the correlation of μ and β at RT with GeON and GeO_2 interface.

4. Conclusions

The low field drain current noise (ΔI_D) is completely governed by the absolute mobility values (μ). At high field in Ge, as opposed to Si, the above dependence fails and the ΔI_D follows the number fluctuation. This is likely due to higher trap density close to the E_c than Si and also due to low conduction band offset at Ge/GeON and Ge/GeO_2 interface, leading to enhanced carrier trapping/detrapping due to tunneling.

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