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P11-2

Low-Frequency Noise Analysis of Si/SiGe pMOSFETs for RF Circuits

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1. Introduction

Strained Si/SiGe MOSFETs have been demonstrated to have enhanced carrier mobility, high field drift velocity, and suppressed short channel effects as compared to bulk Si devices, which are great benefits for RF/microwave telecommunication circuit applications. In addition to enhanced carrier transport properties and low power consumption, low frequency noise performance of SiGe MOSFETs is also very important in RF and microwave circuit applications because it is an important parameter for analogue applications, particularly for mixer and signal generation circuits where the low frequency noise causes an unwanted phase modulation of the signal thus providing a limit on high speed communications.

In this work, low frequency flicker noise characteristics of 0.1 μm $Si_{1-x}Ge_x$ channel pMOSFETs were studied by numerical simulations in the framework of the carrier number fluctuation model as well as the correlated fluctuation in the mobility model [1]. Taking the high field effects into account, the overall power spectral density of the normalized drain current noise (S_{ID}/I_D^2) for short channel MOSFETs is given by:

$$\frac{S_{I_D}}{I_D^2}=\frac{\lambda kT}{2fWL^2}\int_0^L N_t(E_{fp},y)\left\{\frac{1}{N(y)}+\alpha(N)\mu(E_y)\right\}^2 dy \quad (1)$$

where λ is about 1Å for carrier tunneling at the $Si\text{-}SiO_2$ interface, N the number of carriers per unit area in the inverted channel, μ the carrier mobility, E_y the lateral E field along the channel, and N_t the oxide trap concentration per unit volume in the oxide. Fluctuation in the occupancy of the oxide traps induces correlated fluctuations in the carrier number and surface mobility. The mobility scattering parameter, α, represents the influence of the oxide states on the carrier mobility. The device electrical data (N, μ, E_{fp}) at a certain bias point were extracted by Medici simulation [2]. To account for the contribution of velocity overshoot effect in small geometry devices, the hydrodynamic model, which includes the effects of local carrier heating by self-consistent solution of the drift-diffusion and energy balance equations, was used in the majority of calculations. The input referred noise power (S_{VG}) could be obtained by dividing S_{ID} by the square of the transconductance.

2. Simulations and Results

The simulated device structure consists of a 1 nm Si cap layer and a 5 nm strained $Si_{1-x}Ge_x$ ($0 \le x \le 0.5$) channel on top of n-type Si buffer. A retrograde doping profile is used in the channel design and a gate oxide thickness of 30 Å and a p^+-polysilicon gate were chosen to obtain threshold voltage of 0.3 V for 0.1 μm $Si_{1-x}Ge_x$ pMOSFETs at 1.2 V operation.

Low frequency noise characteristics of $Si_{1-x}Ge_x$ pMOSFETs operated in linear and saturation regimes were simulated and compared to their counterpart Si bulk devices. It is clearly to see that the low frequency noise spectral S_{ID}/I_D^2 of $Si_{1-x}Ge_x$ pMOSFETs are significantly lower than the case of Si bulk devices over the entire range of gate overdrive and decrease with increasing Ge content in the $Si_{1-x}Ge_x$ channel (Fig. 1), which is in good agreement with the experimental data reported by Mathew et al [3]. A detail examination of the flicker noise equation shows that this improvement of flicker noise in SiGe channel is not simply due to the charge separation or mobility enhancement of the SiGe channel, but is mainly attributed to less effective oxide trap density for noise generation due to the increasing separation of quasi-fermi level and valence band edge at $Si\text{-}SiO_2$ interface by Ge-induced band offset as shown in Fig. 2. This Ge-induced valence band offset effectively pulls the hole quasi-fermi level away from the valence band edge at the Si/SiO_2 interface and towards the midgap region, hence reducing the oxide trap density effective for noise generation. As for the input referred voltage noise S_{VG}, the improvement is further enhanced by the higher transconductance resulting from the higher intrinsic mobility in $Si_{1-x}Ge_x$ channels as shown in Fig. 3.

The noise S_{ID} for $Si_{1-x}Ge_x$ MOSFETs at V_{ds} = -1.2 V is smaller by 20~50% over a wide range of gate overdrive as compared to the case of V_{ds} = -0.05 V. This is because that the mobility-induced noise contribution is suppressed at high lateral fields present in short channel devices and the carrier number perturbation noise does not increase appreciably in the saturation region due to strong drain induced barrier lowering (DIBL). The tendency of noise reduction for $Si_{1-x}Ge_x$ pMOSFETs is suppressed with increasing Ge contents. The reduction of mobility-induced noise contribution at high fields for short $Si_{1-x}Ge_x$ channel devices is suppressed due to pronounced carrier velocity overshoot effect, and higher carrier number perturbation noise is resulted from improved DIBL effects due to better carrier confinement in $Si_{1-x}Ge_x$ channel, which in turn cause higher potential barrier for holes flowing from source to drain (Fig. 4) and less carrier density at the drain side.

4. Conclusions

Numerical simulation has been performed to investigate the low frequency noise performance of 0.1 μm $Si_{1-x}Ge_x$ pMOSFETs, and it indicated that improved low frequency noise performance could be offered by $Si_{1-x}Ge_x$ channels due to less effective oxide trap density for noise generation, which is resulted from the increasing separation of quasi-fermi level and valence band edge at $Si\text{-}SiO_2$ interface by Ge-induced band offset.

Acknowledgments

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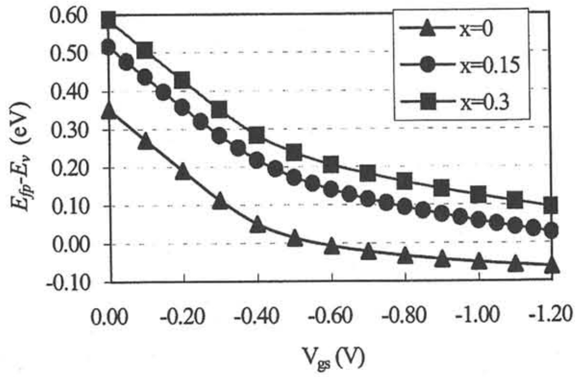

Fig. 2 Separation of the quasi-fermi level of holes (E_{fp}) with respect to the valence band edge (E_V) at the surface as a function of gate voltage for $Si_{1-x}Ge_x$ MOSFETs.

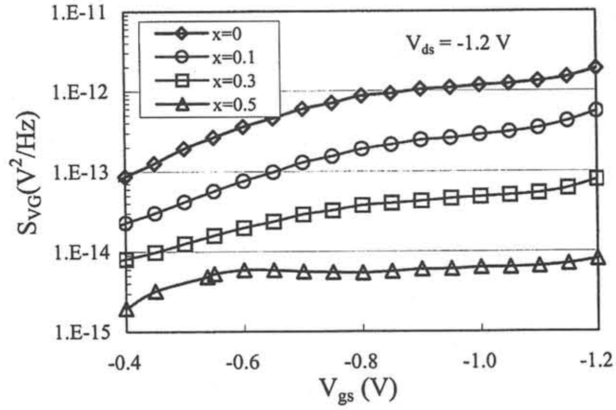

Fig. 3 The spectral density of input referred noise voltage simulated at f = 10 Hz for 0.1 μm p-channel $Si_{1-x}Ge_x$ MOSFETs.

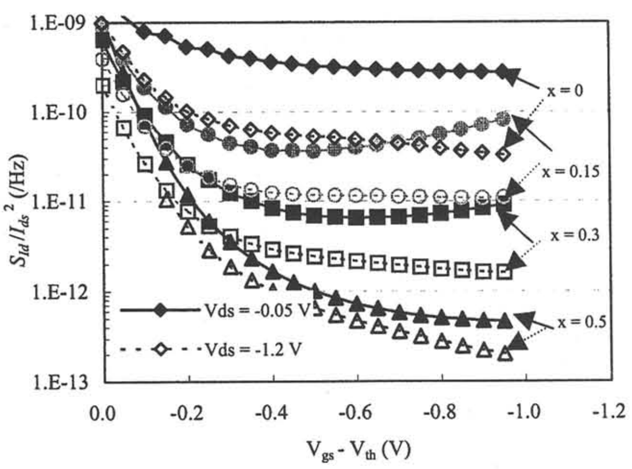

Fig. 1 Normalized current noise power spectral density as a function of gate voltage simulated at f = 10 Hz for 0.1 μm p-channel $Si_{1-x}Ge_x$ MOSFETs at V_{ds} = -0.05 V and V_{ds} = -1.2 V.

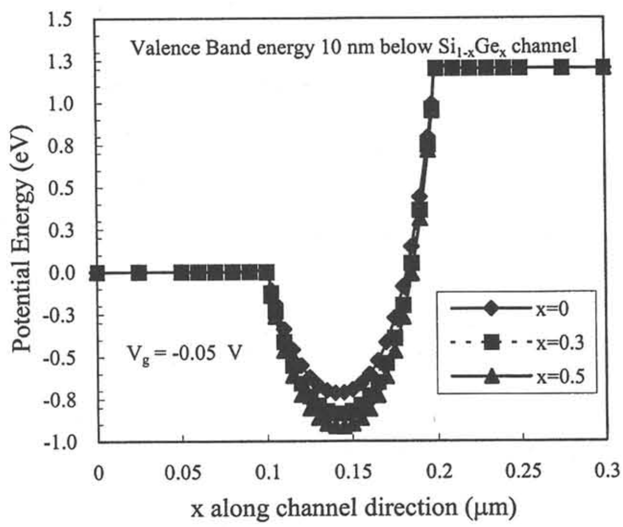

Fig. 4 Energy potential profiles along the channels for the Si $Si_{1-x}Ge_x$ MOSFETs. V_{th} is the same for these devices.