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Impact of Ge Content on Flicker Noise Behavior in Strained-SiGe pMOSFETs

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1. Introduction

Methods of optimizing channel mobility need to be explored in order to overcome the limitations on the scaling down of devices and further improve the speed of complementary metal-oxide-semiconductor (CMOS) circuits. A promising candidate to reach this demand is to exploit the strain-induced band-structure modification. It is shown that p-type metal-oxide-semiconductor field effect transistors (pMOSFETs) with biaxial compressively stress in a SiGe layer [1-2] exhibit improved drive current due to the enhancement in hole mobility. On the other hand, flicker (1/*f*) noise is one kind of low frequency noise which has been the subject of many works during the past years in semiconductor devices [3-4]. As a result to the mobility enhancement, the SiGe pMOSFET is expected to exhibit an improved 1/*f* noise characteristic [5], which is important in analog applications such as mixer and signal generation circuits.

In this work, the 1/*f* noise mechanism observed in strained-SiGe device is presented. Compared to Si control devices, strained-SiGe devices exhibit lower 1/f noise level due to holes in strained-SiGe devices are mainly confined in SiGe channel away from Si/SiO_2 interface where many defects and traps are located.

2. Device Fabrications

Devices were fabricated in a CMOS process based on UHVCVD for epitaxial growth of SiGe and Si layers. The schematic cross-sectional view of compressively strained-SiGe pMOSFET was shown in Fig. 1. The Ge content of compressively strained-SiGe layer is 15% and 30%. For comparison, the Si control devices without SiGe film growth are also investigated.

3. Results and discussion

Fig. 2 show the hole mobility curve in the strained-SiGe pMOSFETs, it was extracted from a long-channel device of L = 100 μm and W = 200 μm by a split capacitance-voltage (C-V) method. Obviously, The SiGe device structures have higher effective hole mobility than the Si-control device, and higher Ge content sample exhibits larger mobility enhancement. The mobility enhancement for strained-SiGe devices with Ge 15% and 30% are about 24%, 45% under an electric field up to 0.6 MV/cm, respectively. This is mainly due to holes reside primarily in the higher mobility SiGe layer over a large gate-voltage range, and higher Ge content sample has higher compressive strain, which leads to larger interband splitting and greater mobility.

The normalized drain current noise spectral density (S_{ID}/I_D^2) versus frequency for strained-SiGe and Si control devices are shown in Fig. 3. As experimentally observed, strained-SiGe devices has a lower noise level compared to Si control, which can be explained by Fig. 4. Due to more carriers are confined in SiGe channel in strained-SiGe devices, carriers transport away from Si/SiO_2 interface where there are many defects and traps at Si/SiO_2 interface, thus suppressing noise level. Moreover, the extracted γ value closely to unity for all devices indicates that 1/f noise is the major source for our devices at low frequency regime. On the other hand, adequate noise model to describe the noise behavior is needed. A typical normalized power spectral density S_{ID}/I_D^2 of drain current fluctuations and the corresponding $(g_m/I_D)^2$ ration versus drain current is presented in Fig. 5. Observed the leveling off at low I_D and the parallelism with the square of the transconductance to drain ratio was found in all devices, which indicates that the behavior of 1/*f* noise can only describe by the carrier number fluctuations [4].

In order to prove further the noise mechanism, the number fluctuation model including correlated mobility fluctuations takes the following forms [4]:

$$\frac{S_{I_D}}{I_D^2} = \frac{q^2 N_t kT\lambda}{WLC_{ox}^2 f^{\gamma}}(1+\alpha C_{OX}\mu_{eff}\frac{I_D}{g_m})^2(\frac{g_m}{I_D})^2 \quad (1)$$

Where α is a Coulomb scattering coefficient. A larger α value indicates that there appears to be evidence for correlated mobility fluctuations and instead the noise is dominated by the conventional number fluctuation term. Extraction of equivalent oxide traps per unit area N_t and Coulomb scattering coefficient α, as a function of the Ge content are shown in Fig 6. As expected, SiGe device with 30% Ge concentration exhibits the lowest α value. This is attributed to the fact that the devices have small effective mass, resulting from the SiGe channel under going a stronger biaxial compressive strain. According to the According to theoretical calculations [6], the smaller the effective mass is, the reduced the scattering. This is the reason that SiGe devices with 30% exhibit improved 1/f noise performance.

4. Conclusions

The strained-SiGe pMOSFETs have been demonstrated enhance device performances and reduce short channel effect. For 1/*f* noise characteristics, the noise level of strained-SiGe PMOSFETs is lower than Si control ones due to carrier confinement in SiGe buried channel. As Ge content increases, noise behavior changes gradually from carrier number fluctuations correlated mobility fluctuations at strong inversion region.

Acknowledgements

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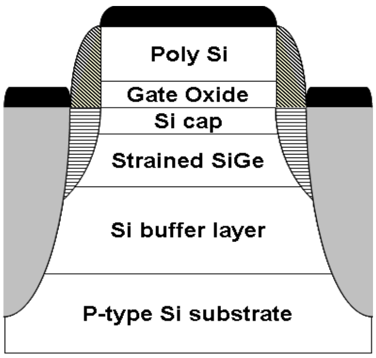

Fig. 1 The schematic cross-sectional view of compressively strained-SiGe pMOSFET.

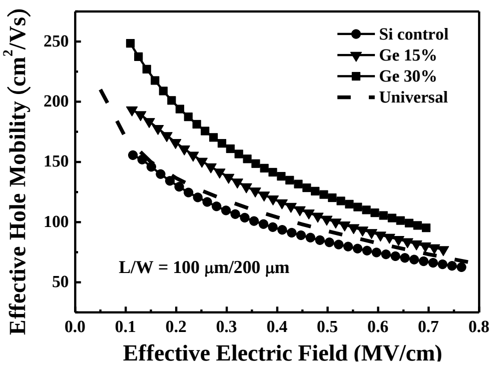

Fig. 2 Effective hole mobility for strained-SiGe and Si control devices as a function of effective field.

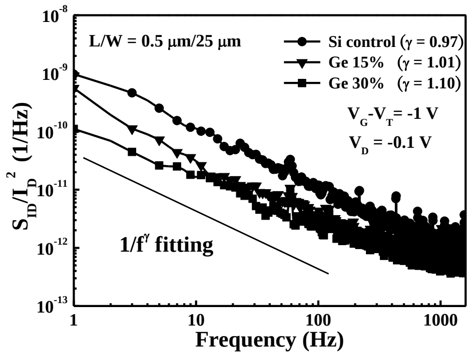

Fig. 3 Normalized Drain current noise spectral density versus frequency for strained-SiGe and Si control devices.

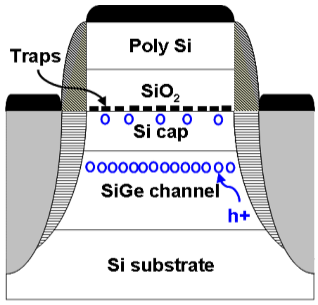

Fig. 4 The schematic diagram to represent carrier transport for strained-SiGe devices.

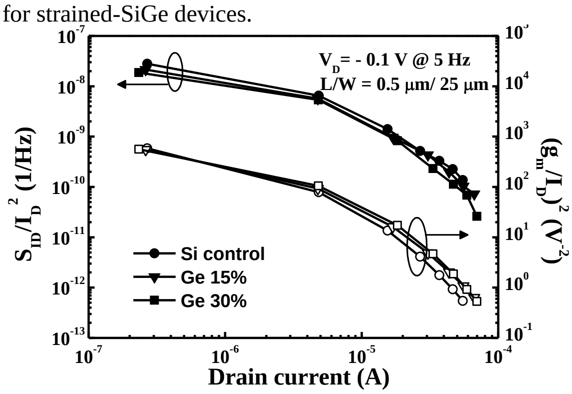

Fig. 5 Normalized Drain current noise spectral density and transconductance to drain current ratio squared versus drain current for strained-SiGe and Si control devices.

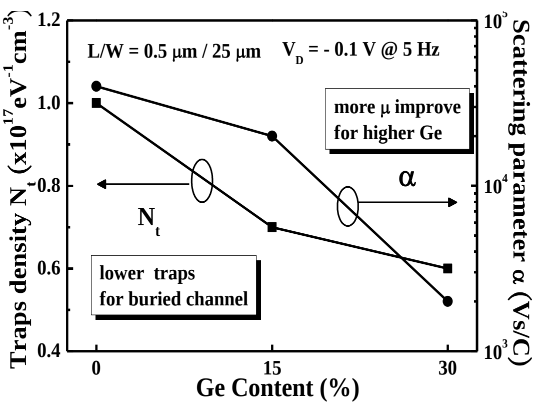

Fig. 6 Traps density and scattering parameter as function of Ge content for strained-SiGe and Si control devices.