Enhanced Carrier-Mobility-Fluctuation Origin Low-Frequency Noise in Uniaxial Strained PMOSFETs

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***Abstract*—This letter reports our new findings on the impact of uniaxial strain on the low-frequency-noise characteristics in nanoscale PMOSFETs. It is found that the normalized drain current noise of the strained device in the high-gate-overdrive (V_{gst}) regime is larger than its control counterpart. In addition, the enhanced carrier-mobility-fluctuation origin $1/f$ noise for the strained device in the high-$|V_{\mathrm{gst}}|$ regime indicates that the carrier mobility in the strained device is more phonon limited, which represents an intrinsic strain effect on the low-frequency noise.**

***Index Terms*—Carrier mobility fluctuation, low-frequency noise, process-induced strain, uniaxial strained PMOSFET.**

I. Introduction

The low-frequency noise in nanoscale CMOS devices is becoming increasingly important because it may limit the functionality of analog and digital circuits [1]. As process-induced uniaxial strained silicon is widely used in the state-of-the-art CMOS technologies to enable mobility scaling, the low-frequency-noise performance for strained devices is particularly important. Although the low-frequency noise is strongly dependent on the device fabrication processes [2]–[4], [13], [14], our pervious study showed that the carrier-number-fluctuation origin input-referred voltage noise of the uniaxial compressive strained PMOSFETs can be improved intrinsically by reducing the tunneling attenuation length [5] through the strain-increased out-of-plane effective mass and tunneling barrier height [5], [6]. Nevertheless, the carrier-number-fluctuation origin low-frequency noise only dominates in the low-gate-voltage-overdrive (V_{gst}) regime. In other words, whether there exists an intrinsic strain effect on the low-frequency-noise characteristics in the high-V_{gst} regime is still not clear and merits investigation. In this letter, we report our new findings on the intrinsic effects of uniaxial strain on low-frequency noise in nanoscale PMOSFETs.

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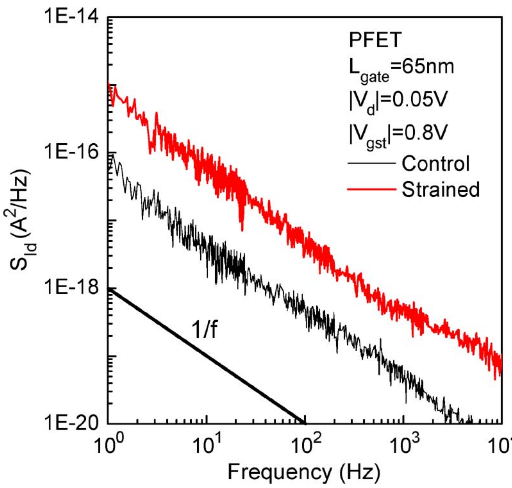

Fig. 1. Drain current noise spectral density S_{Id} for devices with $L_{\mathrm{gate}} =$ 65 nm at $|V_d| = 0.05$ V and $|V_{\mathrm{gst}}| = 0.8$ V, showing typical $1/f^r$ noise type with r close to one.

II. Devices

Coprocessed uniaxial strained and unstrained PMOSFETs are investigated in this letter [5], [7], [8]. The strained and unstrained devices with channel direction $\langle 110 \rangle$ were fabricated on (100) silicon substrate. The strained device features compressive uniaxial contact etch stop layer and SiGe source/drain. For the transistors with gate length $L_{\mathrm{gate}} = 65$ nm, the saturation drain current (I_{dsat}) of the strained device is improved to more than 100% as compared with its control counterpart. Low-frequency-noise measurements were carried out using the BTA9812 measurement system [2].

III. Results and Discussion

The drain current noise spectral densities (S_{Id}) for the strained and unstrained devices with $L_{\mathrm{gate}} = 65$ nm biased at gate overdrive $|V_{\mathrm{gst}}| = 0.8$ V are shown in Fig. 1. The spectra show typical $1/f^r$ noise type with the frequency index γ close to one. Fig. 2 shows the normalized drain current noise spectral density (S_{Id}/I_d^2) versus $|V_{\mathrm{gst}}|$ from the average of ten devices. It can be seen that the strained device shows larger S_{Id}/I_d^2 than its control counterpart in this high-gate-voltage-overdrive regime.

Fig. 3 shows the input-referred noise spectral density for the strained and unstrained devices. The gate-bias-dependent S_{Vg} as $|V_{\mathrm{gst}}|$ larger than ~0.2V for both the strained and

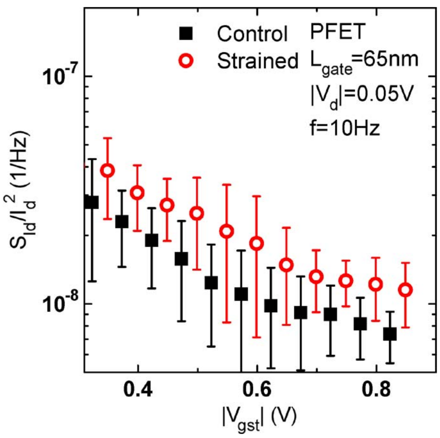

Fig. 2. Normalized drain current noise spectral density $S_{\rm Id}/I_d^2$ versus $|V_{\rm gst}|$ for devices with $L_{\rm gate} = 65$ nm at $f = 10$ Hz and $|V_d| = 0.05$ V.

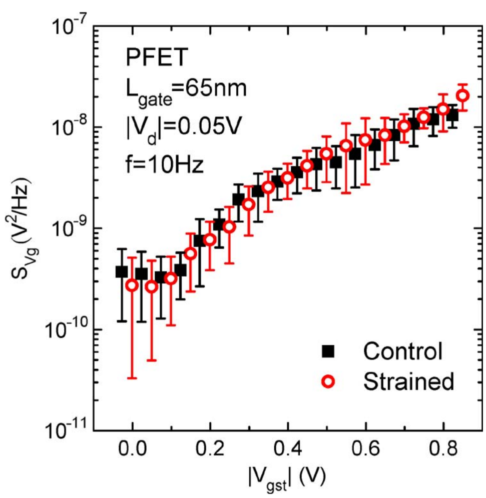

Fig. 3. Input-referred noise spectral density $S_{\rm Vg}$ versus $|V_{\rm gst}|$ for devices with $L_{\rm gate} = 65$ nm at $f = 10$ Hz and $|V_d| = 0.05$ V.

unstrained devices indicates the carrier-mobility-fluctuation origin of low-frequency noise. According to Hooge's carrier-mobility-fluctuation noise model [9], [10], Hooge parameter α_H is a figure of merit for low-frequency-noise comparison. Fig. 4 shows the extracted Hooge parameter [9] versus $|V_{\rm gst}|$ from the average of ten devices. It can be seen that the α_H shows weak $V_{\rm gst}$ dependence, which is also a signature of the carrier-mobility-fluctuation origin $1/f$ noise. Moreover, the strained device shows larger α_H than the unstrained one. It indicates that the carrier mobility for the strained device, as compared with the unstrained one, is more phonon-scattering limited [9], [10]. Through Monte Carlo analysis, Fischetti *et al.* [11] has reported that the only scattering mechanism that is sufficiently sensitive to strain is the scattering from surface roughness [12]. It is plausible that the larger enhancement in the surface roughness mobility results in the more phonon-scattering-limited carrier mobility for the strained device.

Fig. 5 shows the comparison of the α_H's of the strained and unstrained devices with various gate lengths at $|V_{\rm gst}| = 0.8$ V. It can be seen that the impact of strain on α_H increases as gate length decreases. This is because the process-induced strain has

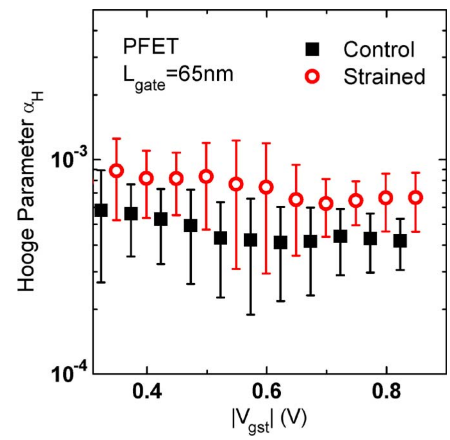

Fig. 4. Hooge parameter versus $|V_{\rm gst}|$ showing larger mobility fluctuations for the strained devices.

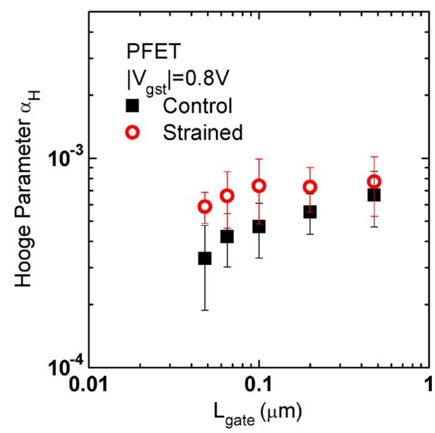

Fig. 5. Hooge parameter versus $L_{\rm gate}$ for strained and unstrained devices biased at $|V_{\rm gst}| = 0.8$ V.

a local nature, and the strain increases with decreasing gate length.

IV. Conclusion

We have reported new findings on the impact of uniaxial strain on the low-frequency-noise characteristics in nanoscale PMOSFETs. It is found that the normalized drain current noise of the strained device in the high-gate-overdrive $(V_{\rm gst})$ regime is larger than its control counterpart. In addition, the enhanced carrier-mobility-fluctuation origin $1/f$ noise for the strained device in the high-$|V_{\rm gst}|$ regime indicates that the carrier mobility in the strained device is more phonon limited, which represents an intrinsic strain effect on the low-frequency noise.

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