Investigation of Temperature Dependence on DC and Low-Frequency Noise Characteristics in Uniaxial Tensile Strained nMOSFETs

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1. Introduction

The continued shrinking of conventional CMOS devices to achieve enhanced performance has revealed limitations, strain engineering provides the promising method for improving device performance stemming from mobility enhancement [1, 2]. The deposited highly tensile stress SiN film as the contact etch-stop layer (CESL) has attracted much interest because it can provide a significant performance boost for nMOSFETs [3, 4]. On the other hand, the low-frequency (1/f) noise is also a concern for continuously scaling down CMOS devices [5]. This is due to the 1/f noise increases as the reciprocal of the device area, which may lead to serious limitation of functionality of the analog, digital, mixed-signal, and RF circuits [6].

In general, Si devices exhibit better performances at low temperatures due to higher carrier mobility [7] and reduced leakage currents [8]. However, with the expansion of electronics into new areas, Si-based electronic devices are now used extensively in many hostile environments, in particular under temperatures exceeding normal operating range. The behaviors of devices operating under high temperature are necessary to be addressed, but relatively little literatures are available for not only DC but also 1/f noise characteristics of strained devices. In this paper, we explore the effect of temperature on the DC and 1/f characteristics of uniaxial tensile strained nMOSFETs.

2. Experiment

The nMOSFETs used in this work were fabricated by the 40-nm technology CMOS process. During the process of CESL, the SiN film with and without tensile stress were deposited on strained and unstrained nMOSFETs, respectively, i.e., CESL and Control devices. All the devices have the same equivalent oxide thickness (EOT) of 1.7 nm. All the devices were characterized by an on-wafer test under the temperature ranging from 298 K to 398 K. The 1/f noise measurements in a frequency range of 1 Hz to 1 kHz were carried out using the battery-powered SR570 Low-Noise Current Preamplifiers and the Agilent 35670A Dynamic Signal Analyzer.

3. Results and Discussion

Fig. 1 shows the drain current ($I_D$) variation with temperature of Control and CESL devices at a fixed gate voltage overdrive, $V_{G-S} = V_G - V_T = 1$ V and $V_{D-S} = 1$ V using the same gate width to gate length ratio of 1 $\mu$m/0.044 $\mu$m. The enhanced $I_D$ observed from the CESL device indicates higher tensile stress in the channel, proving CESL-process-induced tensile stress still slightly transferred to channel even if the gate length is longer, and further exerts its influence as temperature increased. Moreover, the $S_{\nu_\gamma}$ can be expressed as [5]

$$S_{\nu_\gamma} = \frac{q^2 k T}{W L C_{ox} f} \frac{\partial N_e}{\partial V} (1 + \alpha N_e C_{ox} (V_T - V))^2$$

where $\lambda$ is the tunneling attenuation length, $N_e$ is the oxide trap density, $\alpha$ is the scattering coefficient, and $\mu$ is the carrier mobility. According to the Eq. (1), as shown in Fig. 8, the slope of $S_{\nu_\gamma}$ in the region II can be determined by $\partial^2 N_e / \partial V^2$ and $\alpha N_e$ in the Control device. The lower $S_{\nu_\gamma}$ level at high temperature indicates the reduced $\lambda$ because the $N_e$ can be excited from the comparable amount between both devices under various temperature as shown in Fig. 9. As temperature increased, the slightly smaller curvature of $S_{\nu_\gamma}$ of CESL device in the region II indicates the product of $\mu N_e$ is smaller than that of Control device. It can be ascribed by the stress induced lower carrier scattering and increased mobility at the same time. Consequently, the better 1/f noise behavior of strained device at high
temperature can be observed, and it can be expected the further pronounced improvement in short channel nMOSFETs with process-induced tensile stress.

4. Conclusions

In this paper, we have investigated the temperature dependence of DC and 1/f noise characteristics of uniaxial tensile strained nMOSFETs. Based on our experiment results, it is found that the strained device exhibits less sensitivity to temperature, including driving current and gate leakage current. Besides, the improved 1/f noise is also observed at higher temperature. These results present the intrinsic benefits of process-induced strained device operating at high temperature.

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References