Effectiveness of surface potential fluctuation for representing inversion-layer mobility limited by Coulomb scattering in MOSFETs

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INTRODUCTION It is known that this inversion-layer mobility degrades under electrical stress such as Fowler-Nordheim (FN) stress [1-3]. It has been reported for Si n-MOSFETs [1] that mobility limited by Coulomb scattering ($\mu_{coulomb}$) is inversely proportional to the threshold voltage shift (ΔV_{th}) under the positive FN stress. This relationship comes from the fact that both ΔV_{th} and $\mu_{coulomb}$ are quantitatively determined by the amount of interface charges generated by FN stress. However, it should be noted that negative and positive interface charges can compensate each other for ΔV_{th}, while $\mu_{coulomb}$ is limited by the sum of the absolute values of negative and positive interface charges. These facts suggest that, in case that negative and positive interface charges coexist, $\mu_{coulomb}$ cannot be inversely proportional to ΔV_{th}. However, to our best knowledge, there is no report on the validity of ΔV_{th} as an appropriate parameter to represent $\mu_{coulomb}$ in MOSFETs.

On the other hand, the information on MOS interface charges can be obtained from conductance method [4, 5]. It has been reported, in particular, that the amount of surface potential fluctuation σ_s determined by the conductance method can be proportional to the square root of the sum of the absolute values of positive and negative interface charges [4, 5]. This fact suggests that σ_s could be used to represent $\mu_{coulomb}$ with MOS interface charges. However, the relationship σ_s between and $\mu_{coulomb}$ has not been studied yet. In this paper, the effectiveness of σ_s for representing $\mu_{coulomb}$ in Si MOSFETs after FN stress instead of ΔV_{th} is experimentally and systematically examined.

EXPERIMENTAL The samples used in this study were Si nMOSFETs with n^+ ploy Si gates. The gate length/width was 100 μm/100 μm. The gate oxide thickness and doping concentration were 25 nm and 2×10^{16} cm^{-3}, respectively. The condition of FN injection stress was carefully adjusted to generate MOS interface fixed charges. Additionally, in order to generate positive and negative gate oxide fixed charges intentionally, the positive gate FN stress followed by negative gate FN stress was applied. The effective mobility (μ_{eff}) was determined by the split *C-V* method. The values of $\mu_{coulomb}$ were extracted by applying Matthiessen's rule to the initial and stressed μ_{eff}. The values of σ_s were determined by the frequency dependence of the gate conductance of MOSFETs under the depletion condition, according to the method of Brews [5, 6].

RESULTS AND DISCUSSION Fig. 1 shows ΔV_{th} extracted from *C-V* curves of MOSFETs after negative FN stress following positive FN stress. It is observed that the positive ΔV_{th} due to negative fixed charges generated by the positive FN stress, decreases with increasing the negative FN stress time, which is attributable to the compensation of negative interface charges by positive interface charges. On the other hand, μ_{eff} is found to decrease with increasing the negative FN stress time (Fig. 2). The obtained $\mu_{coulomb}$ is confirmed to have $N_S^{0.5}$ dependence (Fig. 3), which is consistent with the reported results of $\mu_{coulomb}$ limited by MOS interface charges [2, 3].

Fig. 4 shows the experimental relationship between ΔV_{th} and $\mu_{coulomb}$ after only positive FN stress and positive + negative FN stress. The inverse of $\mu_{coulomb}$ after only positive FN stress is proportional to ΔV_{th}, as reported in [1]. It is observed, however, that $\mu_{coulomb}$ after the positive + negative FN stress loses the inverse relationship with ΔV_{th}, indicating that ΔV_{th} cannot represent the amount of the Coulomb scattering centers. Fig. 5 shows the relationship between σ_s and $\mu_{coulomb}$ after only positive FN stress and positive + negative FN stress. It is found that $\mu_{coulomb}$ can be described universally as the single line proportional to σ_s^{-2}, irrespective of the only positive or positive + negative FN stress. This result means that σ_s determined by the conductance method is effective in representing $\mu_{coulomb}$ even under coexisting of positive and negative interface charges, because this value is regarded as proportional to the square root of the sum of the absolute values of positive and negative interface charges

CONCLUSION The values of $\mu_{coulomb}$ can be successfully represented by σ_s determined by the conductance method in any conditions of MOS interface charges, while ΔV_{th} fails to represent $\mu_{coulomb}$ under coexisting of positive and negative interface charges.

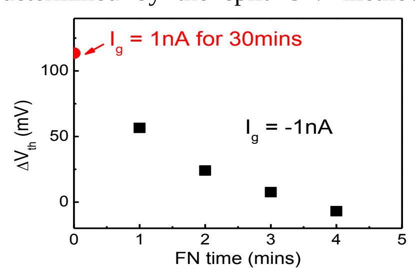

Fig.1. ΔV_{th} extracted from *C-V* curves of MOSFETs

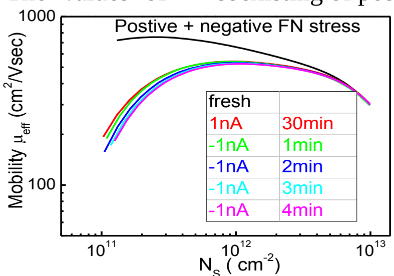

Fig. 2. μ_{eff} extracted from split *C-V* method

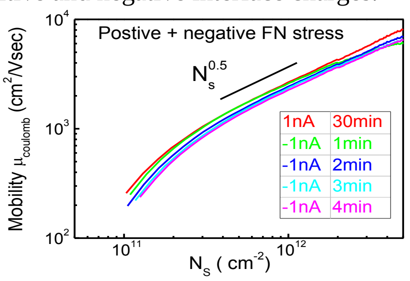

Fig.3. N_s dependency of coulomb mobility

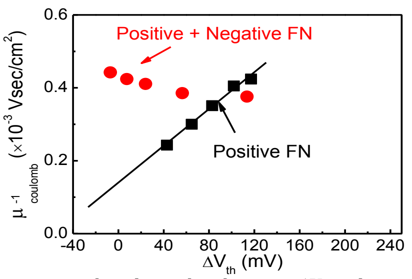

Fig. 4. The relationship between ΔV_{th} and $\mu_{coulomb}$

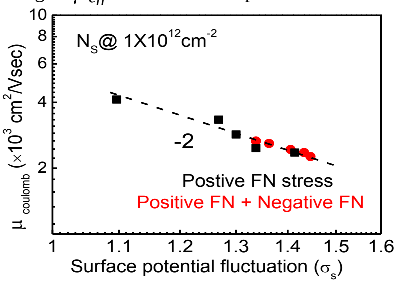

Fig. 5. The relationship between σ_s and $\mu_{coulomb}$

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