A Mobility Model for Submicrometer MOSFET Simulations Including Hot-Carrier-Induced Device Degradation

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The hot-carrier-induced device degradation has become a major problem in scaling of MOSFET's. In conventional structures, Hsu *et al.* [1] pointed out that the mobility degradation due to hot-carrier effects plays an important role in the device degradation. This means that the accurate modeling of the mobility is required in simulating the hot-carrier-induced device degradation.

In this report, we propose a mobility model which includes the surface scattering effects of interfacial charges. The model is extended from an earlier model [2]. The normal electric field dependence of the mobility reduction is as follows,

$$\mu(E_\perp, N) = \frac{\mu(N)}{1 + \alpha \cdot p \cdot \mu(N) \cdot E_\perp (1 + \beta \cdot (E_\perp)^{2/3})^{-1}} \tag{1}$$

$$p = p_0 + \sigma \cdot Nf, \tag{2}$$

here parameter p represents the surface scattering effects. The second term in eq. (2) models Coulomb scattering of the interfacial charges Nf of more than 10^{12} cm^{-2} are generated by the hot-carriers. In order to take account of the screening effect of Coulomb scattering, the scattering cross section σ is related to the carrier density in the inversion layer.

To clarify the screening effect on the mobility degradation, the present model is incorporated in the process/device simulator : SMART [3] and the drain current is simulated before and after stressing. A stress experiment of 10^3-s duration at $V_G = 2.5V$ and $V_D = 5.0V$ was performed on a conventional MOSFET It has a gate length of 0.5 µm and a gate oxide thickness of 10.2nm. The distribution of the trapped charge and the generated interface-state density is calculated under steady-state condition.

In Fig. 1, the drain current degradation is compared with the experimental data and non-screening model. The non-screening model assumed that the scattering cross section is constant. The difference between the two models increases as the gate voltage is increased. In non-screening model, the mobility degradation is induced even in high gate voltage region. In the present model, the screening effect moderates the degradation with the increase of carrier density in the inversion layer. This leads to a good agreement with the experimental data

In addition, the transconductance degradation is calculated as shown in Fig. 2. As the gate voltage is increased, Gm degradation using the present model is suppressed. This is consistent with the experimental data. This characteristics are inherent in the conventional MOSFET's [4]. In the case of non-screening model, the result gives a parallel shift of Gm, which is the inherent characteristics of LDD MOSFET's [4].

To verify the accuracy of the present model for the hot-carrier-induced degradation, the simulated results are compared with experimental I-V characteristics in Fig. 3. In both cases of before and after stressing, the results are in good agreement with experimental

data where the gate bias is between the subthreshold region and the linear region.

In conclusion, a mobility model for submicrometer MOSFET simulations including hot-carrier device degradation has been proposed. The model includes the screening effect of Coulomb scattering. It is shown that the screening effect in the mobility model plays an important role in simulating the drain current associated with the device degradation. The present model allows the simulation of hot-carrier-induced degradation depending on the device structure.

References

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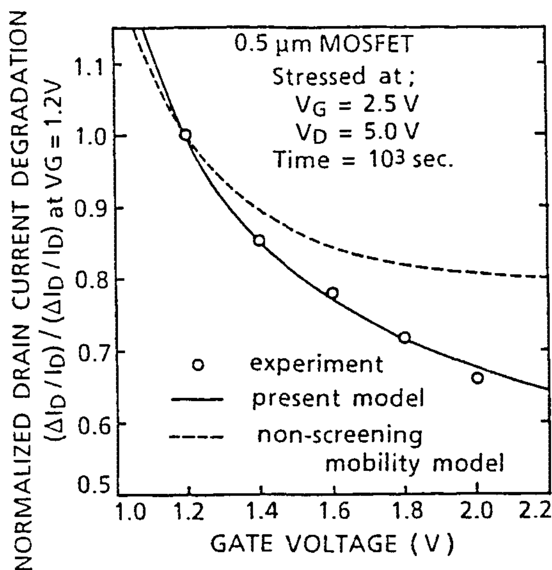

Fig.1 Drain current degradation versus gate voltage. The degradations are normalized by the value of the drain current degradation at $V_G = 1.2V$.

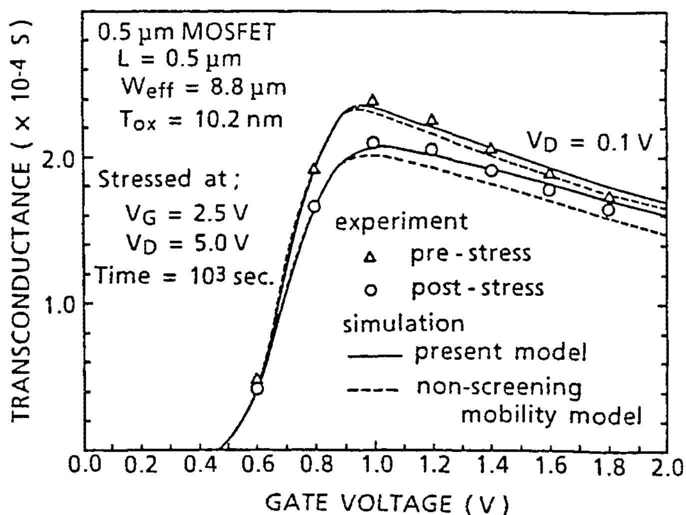

Fig.2 Transconductance versus gate voltage. The transconductance is measured at $V_D = 0.1V$ before and after stressing.

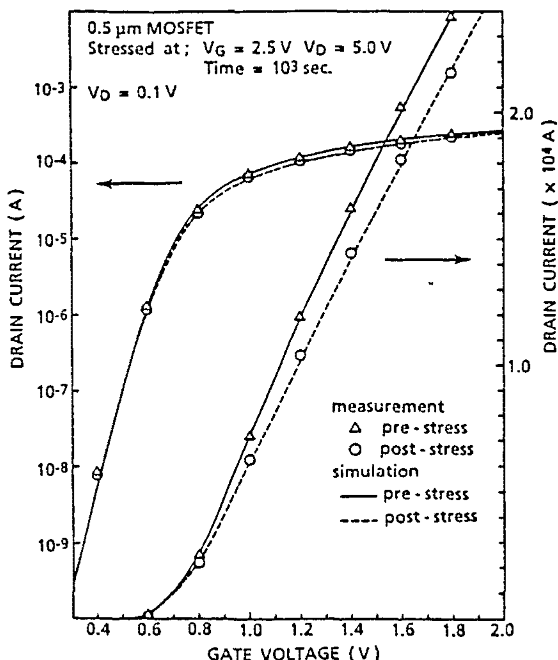

Fig.3 Drain current versus gate voltage. The simulated results are compared with experimental data before and after stressing.