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Mobility Degradation Induced by Substrate-Hot-Electron Generated Interface Traps at Different Stress Voltages and Temperatures

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The electron mobility degradation due to interface traps generated by substrate-hot-electrons injected from a Buried Junction Injector (BJI) structure is investigated. It is the first time to observe the interface trap induced mobility degradation is independent of the stress voltages but is a strong function of the temperatures during substrate-hot-electron stress. Direct linear relationship between mobility degradation and hot-electron generated interface traps is obtained.

INTRODUCTION

The mobility of channel carriers governs the magnitude of the channel current in MOSFET. There have been extensive work on the investigation of factors, such as, oxide charges [1], dipoles, surface roughness [2,], and interface traps in as grown oxides [3,4], which degrade the carrier mobility. However, data are scarce on the relationship between the mobility degradation and the hot-carrier created interface traps [5]. In this paper, we have first employed the hot-electron injection at different oxide voltages and temperatures from a BJI structure (as shown in Fig. 1) to investigate the voltage and temperature dependencies of mobility degradation.

EXPERIMENTS

The BJI devices used in this study were fabricated using a p-well CMOS process. N-channel MOSFETs were built in p-wells on n-epi/n^+ substrates. The fabrication process are identical for both p- and n-type poly-Si gated n-channel devices except for the doping of gate. The gate oxide thickness are 7 and 17nm. P-type poly-Si gate is implanted with 8 KeV boron to a dose of $2x10^{15}/cm^2$, whereas n-type poly-Si gate is implanted with 40 KeV arsenic to a dose of $3x10^{15}/cm^2$. Both devices were subjected to recrystallization anneal for 15 min. in Ar. By using BJI structure, the electron injection is controlled by the vertical bipolar transistor consisting of the channel as a collector, the p-well as a base, and the n-epi as a emitter (as shown in Fig. 1(a)). Electrons injected by the forward biased substrate/well junction are accelerated towards and into the oxide by the reverse bias between the channel and the well, as shown in Fig. 1(b). The oxide field is governed by the voltage between the gate and the channel, and the energy of hot electrons at the SiO_2/Si interface is controlled by the voltage between the channel and the well. In order to increase the hot-electron injection efficiency, the surface impurity doping concentration is raised to $10^{17}/cm^3$ by implantation.

(a)

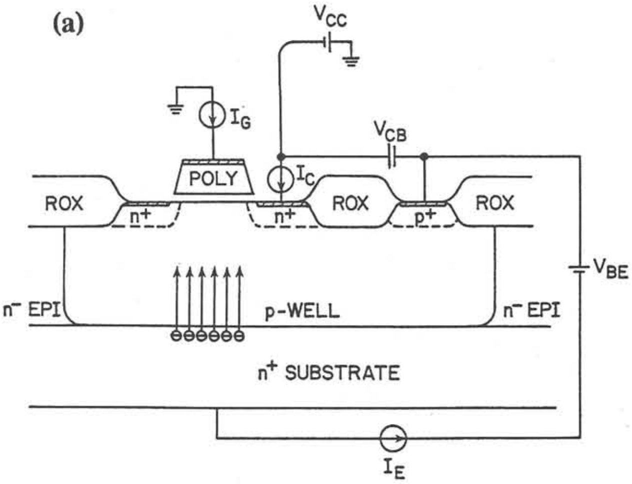
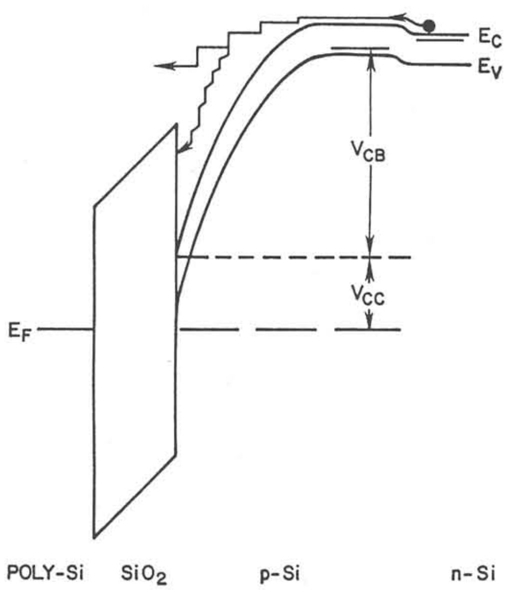


Fig. 1 (a) The cross section and (b) the energy band diagram of Buried Junction Injector during stress.

(b) SUBSTRATE HOT ELECTRON INJECTION FROM BJI



RESULTS AND DISCUSSION

As shown in Fig. 2, the increase of subthreshold slope (S_f-S_i, S_i and S_f: the subthreshold slope before and after stresses) and the decrease of maximum transconductance ((G_{mf} - G_{mi})/G_{mi}, G_{mi} and G_{mf} : transconductance before and after stresses) are enhanced as oxide voltage increases during the hot-electron injection. These results clearly indicated that the mobility degradation increases with the generated interface traps. By applying Mathiessen's rule, we have

$$\mu_f^{-1} = \mu_i^{-1} + \mu_{it}^{-1} \quad (1)$$

where μ_f is the mobility after stress, μ_i before stress, and μ_{it} the mobility due to scattering of generated interface traps. Since G_m is proportional to μ, we have

$$(G_{mf}^{-1} - G_{mi}^{-1}) / G_{mi}^{-1} = \mu_i / \mu_{it}. \quad (2)$$

The generated interface traps can be obtained from the normalized change of subthreshold slope as

$$(S_f - S_i) / S_i = q\, \Delta D_{it} / (C_{OX} + C_D) = K\Delta D_{it}$$

where, C_{OX} is the oxide capacitance, C_D is the semiconductor depletion capacitance, and ΔD_{it} is the generated density of interface traps. By plotting data

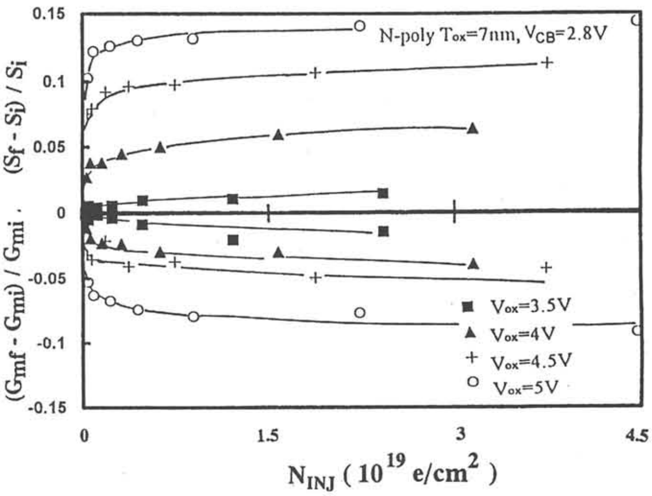


Fig. 2 The hot-electron induced transconductance and subthreshold slope degradation at different voltage stresses.

calculated using (2) against (3), as shown in Fig. 3, it shows that the mobility degradation is a linear function of hot-electron generated interface traps and independent of the stress oxide voltages, that is,

$$\mu_i / \mu_{it} = \Theta K \Delta D_{it}\,;\; \mu_{it} = \mu_i / \Theta K \Delta D_{it}, \quad (4)$$

where Θ is the proportional constant and independent of stress oxide voltage. The independence of the interface trap induced mobility degradation on the stress voltage suggests that the origins of interface straps created by the different oxide voltage stress are the same. The stress-voltage independence of mobility degradation is also observed for the MOSFETs with different oxide thickness and polysilicon gates as shown in Fig. 4 and 5, respectively.

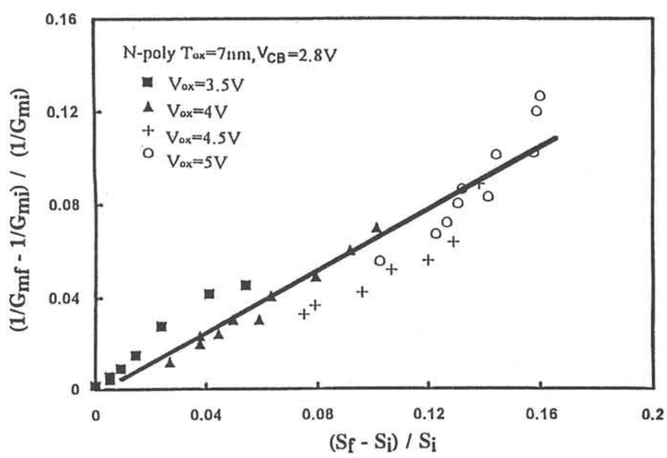


Fig. 3 The mobility degradation as a function of generated interface states during hot-electron stress at different oxide voltages.

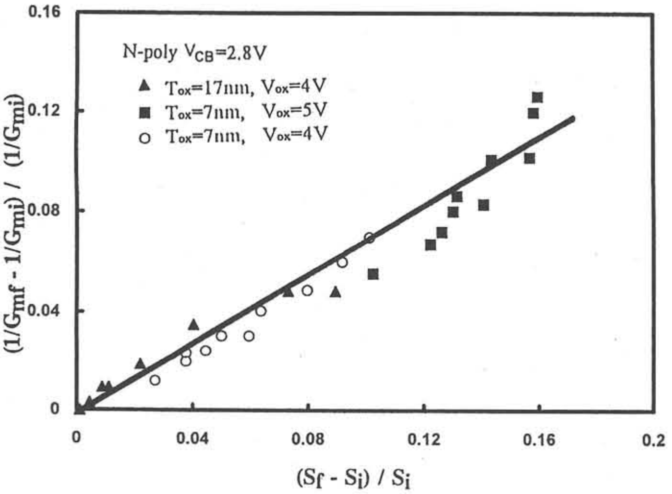


Fig. 4 The interface trap induced mobility degradation of 7 and 17nm oxides stressed at different voltages.

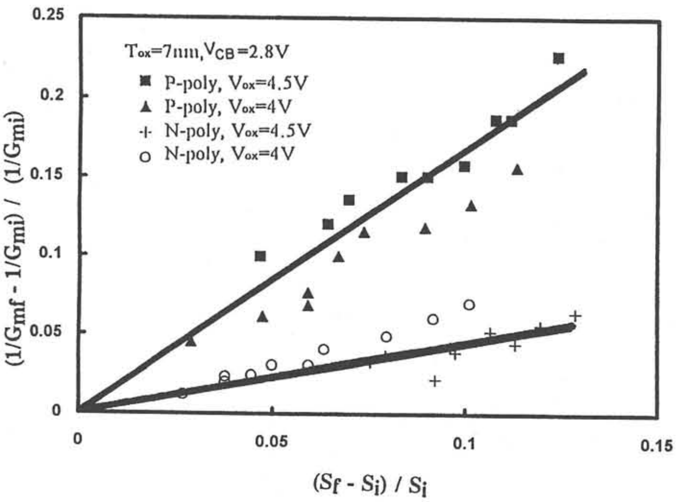


Fig. 5 The interface trap induced mobility degradation of p- and n-poly MOSFETs stressed at different voltages.

The interface trap induced mobility degradation during hot-electron stress at different temperatures are shown in Figs. 6 and 7. The interface trap generation is shown apparently higher, while the mobility degradation is lower at higher temperature stress. This interesting result suggests that the mobility degradation due to hot-electron generated interface trap become less significant as the temperature increases during stress, whereas the mobility degradation is dominated by the lattice scattering as measured at high temperatures.

CONCLUSIONS

In summary, using hot-electron injection from a BJI structure to study the interface trap induced mobility degradation, we have demonstrated that the interface trap induced mobility degradation is independent of stress oxide voltage and established the relationship between the generated interface traps and the degraded mobility. From the temperature dependence of interface trap induced mobility degradation, the interface trap induced mobility degradation is shown to become less significant as the temperature during stress increases.

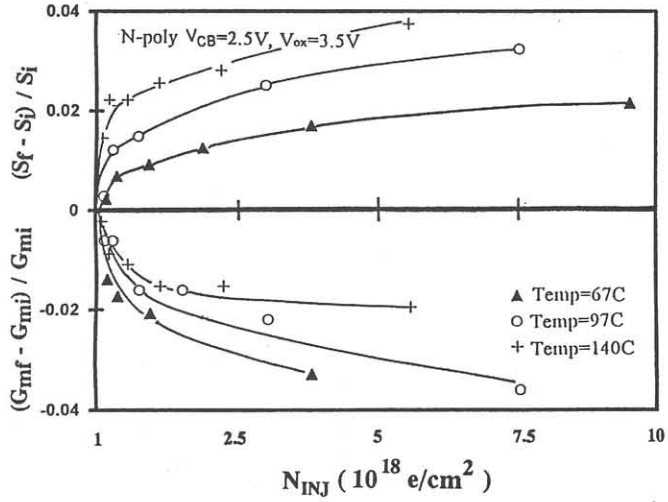


Fig. 6 The hot-electron induced transconductance and subthreshold slope degradation at different temperature stresses.

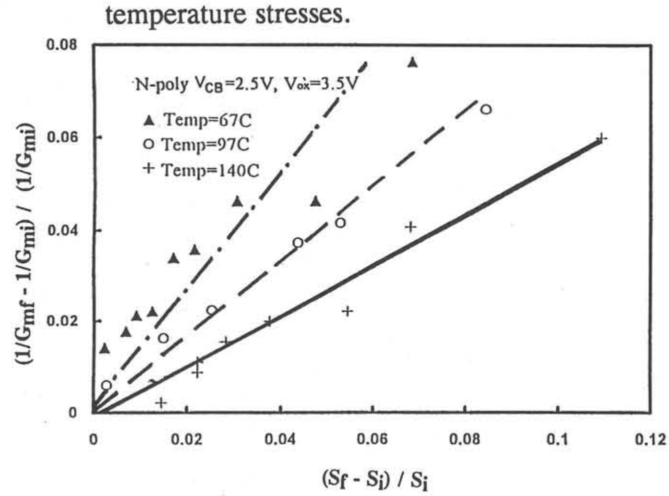


Fig. 7 The mobility degradation as a function of generated interface states during hot-electron stress at different temperatures.

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