Fundamental Limits of Electron Transport in Ultrathin SOI MOSFETs

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The continuous scaling of the MOSFET transistor physical dimensions[1] is the ultimate driving force for the development of the semiconductor industry. The 2001 ITRS roadmap projects the introduction of 70 nm (50 nm) node CMOS devices into production by 2008 (2011). This will require transistors with a physical channel length in the sub-50 nm range, yielding a drain current of 750 µA/µm and operating at extremely low supply voltage (V_{DD} = 0.6–0.9V).

In order to control short channel effects, the scaling of conventional MOSFETs below 70 nm requires channel doping larger than 10^{18} cm^{-3}, which would reduce the effective mobility μ_{eff} and hence adversely affect the device performance.[2] In this dim scenario for the bulk MOSFET, fully depleted single- (SG) and double-gate (DG) SOI transistors realized on ultra-thin silicon films are gaining increasing interest for the sub-50 nm CMOS technologies.[3] The suppression of short channel effects in SOI transistors is obtained using ultra-thin, virtually undoped Si films, resulting in increased mobility and reduced junction capacitance. However, when the silicon film thickness T_{Si} is reduced down to a few nanometers, size-induced quantization begins to affect the inversion layer, so that both threshold voltage and effective mobility show a significant T_{Si} dependence.[4] Although so far the literature has discussed only the qualitative dependence of μ_{eff} on T_{Si},[5] a comparison with experimental data is mandatory for the physical understanding and for the identification of the optimum T_{Si} window for device design.

We will present a microscopic transport model accounting for all the most relevant scattering mechanisms in bulk MOSFETs, that we have further extended to SOI transistors by accounting for the roughness and for the possible interface states at both Si/SiO_2 interfaces. Although the model can satisfactorily reproduce the experimental μ_{eff} of bulk MOSFETs,[2] a systematic comparison with the mobility data of SOI transistors operated in SG and DG mode, reveals that the simulated mobility dependence on T_{Si} is weaker than what is observed in experiments.[4]

We then discuss how the anisotropy of acoustic phonons and the scattering with surface optical (SO) phonons may help to improve the agreement with the experiments.[6] The results indicate that, for small T_{Si}, the SO phonon scattering increases more than the other phonon scattering mechanisms do, yielding an enhanced T_{Si} dependence of the mobility that favorably compares with the SOI transistor experiments.

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