Comparative Study of Low-Field Mobilities in Double- and Single-Gate Ultra-Thin Body SOI for Different Substrate Orientations

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1. Introduction

Mobility in ultra-thin body (UTB) silicon films has been recently the subject of intensive experimental [1,2] and theoretical studies [3-5] because of their superior potential for scaling. Mobility in double-gate (DG) mode is expected to be enhanced as compared to the one in single gate (SG) due to the volume inversion [3]. Recent experiments [2] have confirmed that the DG mobility is indeed higher than the one in SG operation mode for (110) UTB SOI. For (100) SOI DG mobility is, however, inferior to the SG one at high carrier concentrations [1,2]. It was argued [2] that substantially smaller splitting between the lowest primed and unprimed subbands in DG is responsible for the higher occupation of subbands and thus for the mobility lowering at high effective fields. In order to verify this speculation, we have carried out Monte Carlo simulations for (110) and (100) UTB SOI in both SG and DG modes.

2. Method

Degeneracy effects in UTB SOI are of major importance, especially at high effective fields. We are using a Monte Carlo algorithm developed for small signal response calculations [6], which is formally exact in the limit of small driving fields and allows accounting for degeneracy effects and non-parabolic band structures. Since we are mostly interested in mobilities at high carrier concentrations, Coulomb scattering is not included. We consider electron-phonon interactions and surface roughness scattering. The surface roughness is assumed uncorrelated and equal at opposite SOI interfaces. Results of mobility calculations with and without degeneracy effects taken into account are shown in Fig. 1. In case of Boltzmann statistics most of the carriers occupy the lowest subband with the highest mobility even at high effective fields. This leads to a significant mobility overestimation, especially at high effective fields, when an increasing occupation of higher subbands with low effective mobilities drastically reduces the actual mobility in UTB SOI.

3. Results

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Fig. 2 shows the mobility dependence on carrier concentration N_S for several Si film thicknesses T_{SOI}, for (100) SOI in SG mode. Results are in good agreement with previous data from [4]. Fig. 3 displays the mobility for both SG and DG operation modes for (100) SOI together with experimental data as a function of N_S (SG) and $N_S/2$ (DG). For small and moderate carrier concentrations the DG mobility tends to be higher as expected [3]. For high N_S and for thin T_{SOI} the DG mobility is significantly degraded as compared to the SG mode, which is in qualitative agreement with experimental data [1,2]. Note that additional scattering mechanisms must be incorporated in order to achieve a better quantitative agreement with experiments [5].

Fig. 4 displays the mobility in <001> direction for (110) SOI, in both DG and SG modes. The calculated DG mobility is larger in the whole range of N_S, in agreement with experiments [2]. This behavior is consistent with the volume inversion hypothesis [3]. It is unclear why the (100) DG mobility is lower than that in SG mode at high N_S (Fig.3). Fig. 5 shows correlations between the (100) DG mobility degradation and the primed subband occupation increase. Scattering in primed subbands suppresses the mobility enhancement due to the volume inversion in DG.

It was suggested [2] that the higher occupation of the primed ladder in DG is due to a smaller intersubband splitting as compared to the SG. In UTB SOI this effect is relatively small: the subband structure is determined by T_{SOI} wall quantization and is similar in both DG and SG mode. Higher occupancy of primed subbands in DG mode is due to a twice as large carrier concentration than in the SG case, as illustrated in Fig. 6. Thee inset in Fig. 5 displays the relative contributions of two mechanisms to the occupancy of primed subbands in DG mode.

4. Conclusions

Low-field mobility is theoretically predicted for (100) and (110) UTB SOI. It is shown that twice as high carrier concentration in DG mode leads to a higher occupation of primed ladder for (100) UTB SOI and lower DG mobility at high effective fields as compared to its SG counterpart.

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References

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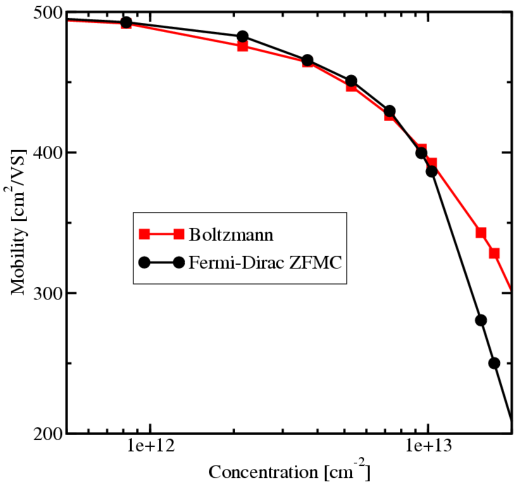

Fig.1: *DG SOI mobility calculated with and without degeneracy effects.*

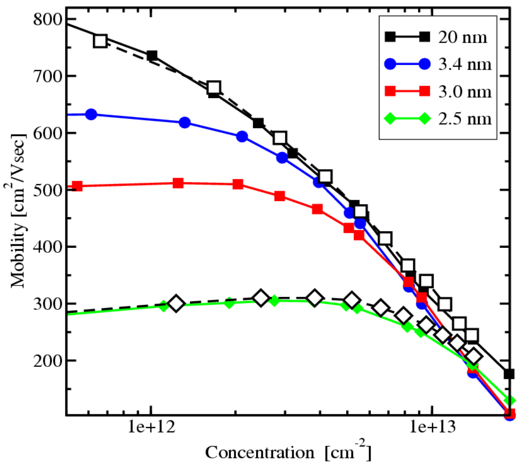

Fig.2: *Mobility dependence on concentration for different Si thicknesses, in SG operation. Results of simulations* [4] *are shown for comparison (open symbols).*

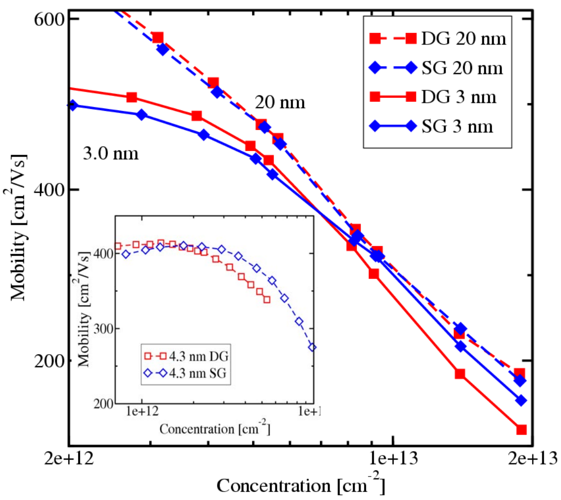

Fig.3: *Mobility for SG (diamonds) and DG SOI (squares) at (100) substrate. For high concentrations, the DG mobility becomes lower than the SG mobility, in qualitative agreement with experiment* [1] *(Inset).*

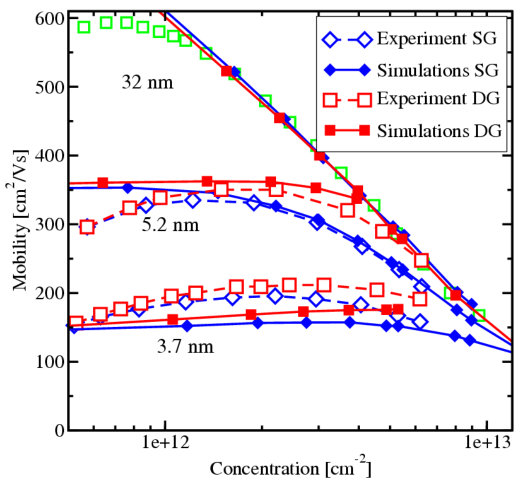

Fig.4: *Mobility at (110) substrate in <001> direction, for different silicon thicknesses. Mobility in DG operation is higher for all* N_S*, in qualitative agreement with recent experiment* [2].

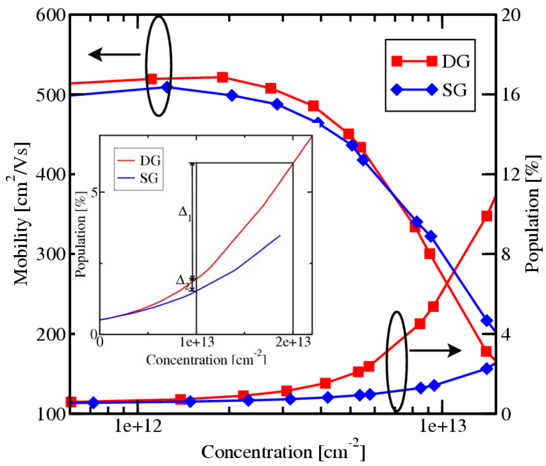

Fig.5: *Mobility and primed subband occupation plotted as function of* N_S *for SG and* $N_S/2$ *for DG (100) SOI with* T_{ox} *= 3nm. Strong correlation between mobility degradation and high occupation of primed subband with efficient scattering is seen. Inset: Primed subband occupation as a function of* N_S *for both SG and DG SOI. Relative contribution* Δ_2 *to due to difference in bandstructure* [2] *in DG is small in comparison to the contribution* Δ_1 *due to doubled concentration.*

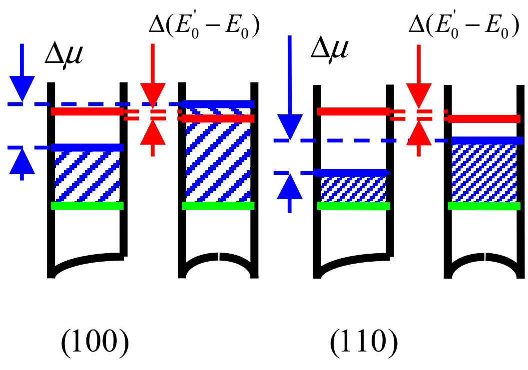

Fig.6: *Schematic band structure in SG (left) and DG (right) UTB SOI. Subband energies are determined by Si film wall quantization and are approximately the same in SG and DG, for similar gate voltages. Higher occupation of primed subands in (100) DG is due to doubled total concentration, as compared to SG, and low density of states in the unprimed subband.*