Mobility Modeling in SOI FETs for Different Substrate Orientations and Strain Conditions

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1. Introduction

Mobility in ultra-thin body (UTB) FETs in double-gate (DG) and single-gate (SG) configuration has been recently the subject of intensive experimental [1,2] and theoretical studies. Mobility in DG devices is expected to be enhanced as compared to the mobility in SG FETs due to volume inversion [3]. Different substrate orientations are also the subject of investigations. Recent experiments [2] have confirmed that the DG mobility is indeed higher than the SG mobility in (110) UTB FETs, whereas at the (100) substrate the DG mobility is inferior compared to the SG mobility at high carrier concentrations [1,2]. Mobility enhancement due to strain engineering is a well established technique used to improve performance of bulk MOSFETs. Due to its industrial importance, the physical reasons of uniaxial strain induced mobility enhancement are becoming the subjects of extensive studies. Influence of stress on transport in UTB FETs is of primary importance because of their potential importance for the far-end ITRS roadmap scaling devices.

2. Method

We have used a subband Monte Carlo algorithm to compute the electron mobility in thin silicon films. The algorithm includes degeneracy effects [4], which are of major importance in UTB FETs, especially at high effective fields. We included electron-phonon and surface roughness scattering. The surface roughness is assumed uncorrelated and equal at opposite UTB film interfaces. The Si band structure under different strain conditions was calculated using the empirical pseudopotential method [5].

3. Results

Fig.1 shows the mobility calculated in a thick silicon film for (100) and (110) substrate orientations. For a 20 nm thick film the mobility in SG mode coincide with the DG mobility, plotted as function of the concentration per channel. Mobility is isotropic for (100) substrate orientation, whereas for (110) a clear anisotropy is displayed. Results of simulations are in good agreement with the experimental data [1,2] also shown in Fig. 1.

We apply uniaxial strain of 0.1 GPa and 1.0 GPa along [110] direction to a thick (001) oriented Si film. Fig.2 demonstrates that the in-plane mobility enhancement is maximal along the strain direction. In the in-plane direction orthogonal to strain the mobility enhancement is less pronounced and may change sign depending on carrier concentration. Fig. 3 displays the in-plane mobility enhancement as function of angle between the strain and current directions, for the two values of strain, at a fixed carrier concentration. The enhancement is clearly anisotropic. Similar anisotropic mobility enhancement under [110] uniaxial stress was recently observed experimentally [6]. This anisotropy can not be explained by the higher subband depopulation due to of strain since the ground subband is isotropic which would inevitably result in isotropic mobility. The only satisfactory explanation for the anisotropic mobility enhancement is the modification of the electronic band structure, which would result in effective mass changes different in the directions parallel and orthogonal to the [110] strain direction.

In order to verify this conclusion, band structure calculations were carried out using our empirical pseudopotential code extended to include strain in arbitrary direction. In-plane effective masses extracted from the band structure calculations show that the otherwise isotropic dispersion is getting warped (Fig. 4). Effective mass decreases in the direction of tensile strain leading to a pronounced mobility enhancement in this direction.

We now analyze the mobility dependence on the Si film thickness. Mobility dependences on charge concentration for (110) substrate are shown in Fig. 5. Mobility, which is anisotropic, is only shown in <001> direction, for different silicon thicknesses. Due to volume inversion [3] the mobility in DG operation is higher for all N_S than the SG mobility, in good agreement with experimental data [2].

Finally, we study the influence of strain on UTB FET mobility. Results of mobility calculations under [110] uniaxial strain applied are shown for two (001) oriented Si body thicknesses. Due to change of effective masses (Fig. 4) induced by strain the substantial in-plane mobility modulation is observed even at 2.4 nm thick Si film. Uniaxial stress is promising technique for mobility engineering in UTB FETs.

This work was supported in part by the Austrian Science Fund FWF, project P17285-N02.

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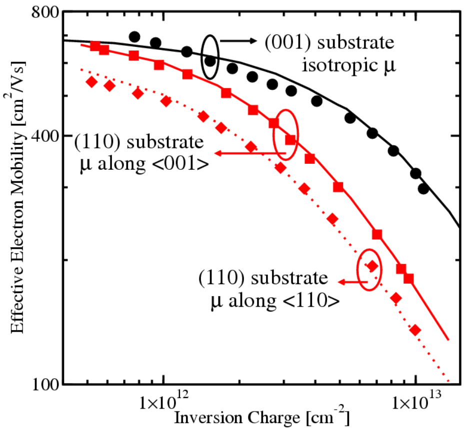

Fig. 1. Simulated mobility for 20 nm thick Si body compared to measurements [1,2] (symbols), for (110) and (110) orientation.

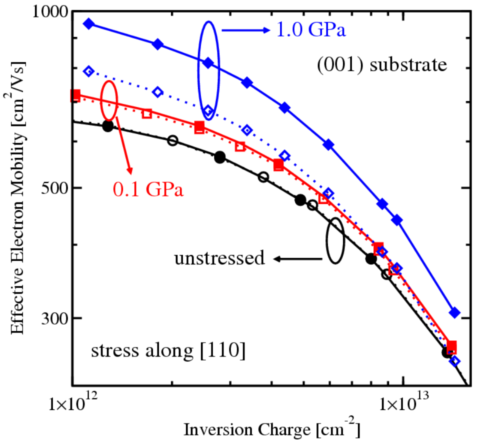

Fig. 2. In-plane mobilities enhancement in 20 nm thick (100) Si film for two values of uniaxial stress along [110].

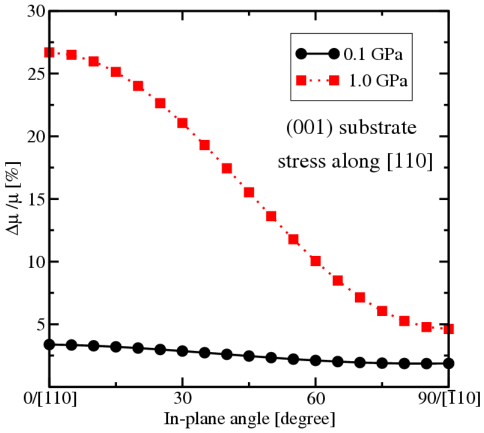

Fig. 3. Mobility enhancement plotted as function of angle between strain [110] direction and current direction.

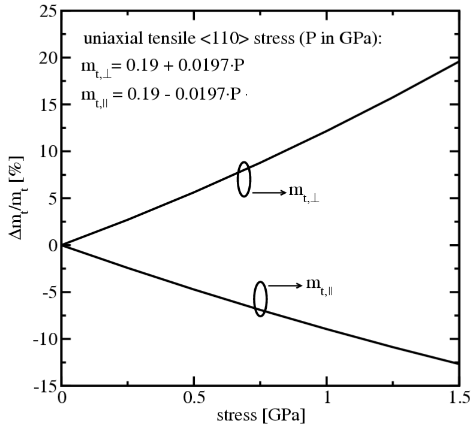

Fig. 4. Relative in-plane electron effective mass change in unprimed subbands on (001) substrate under [100] tensile stress.

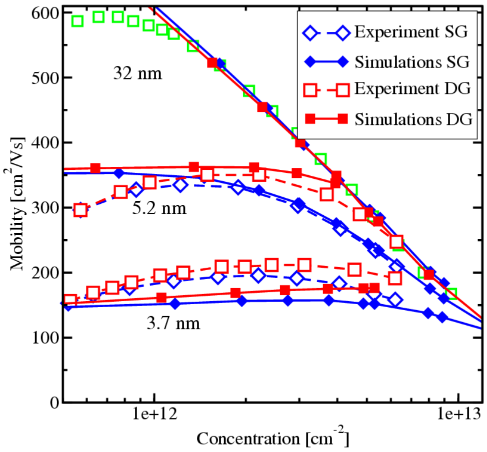

Fig. 5. Mobility at (110) substrate in <001> direction, for different silicon thicknesses. Mobility in DG operation is higher for all N_S, in qualitative agreement with recent experiment [2].

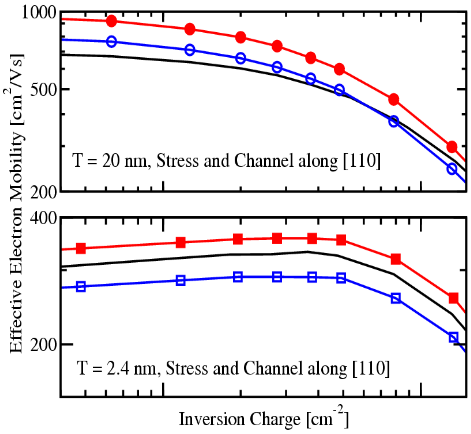

Fig. 6. In-plane mobility change under [110] uniaxial stress in (001) UTB Si film. Substantial mobility change for 2.4 nm UTB can be attributed to the effective mass change.