Enhanced by Shear Strain Splitting of Unprimed Subbands in (001) Silicon Films and Point Contacts

Viktor A. Sverdlov [1], Oskar Baumgartner [1], Thomas Windbacher [1], Franz Schanovski [2], and Siegfried Selberherr [1]

[1] *Institute for Microelectronics*
[2] *Christian Doppler Laboratory for TCAD at the Institute for Microelectronics*
TU Wien, Gußhausstraße 27-29, A-1040 Wien, Austria

With scaling apparently approaching its fundamental limits, the semiconductor industry is facing critical challenges. New engineering solutions and innovative techniques are required to improve CMOS device performance. Spin as a degree of freedom is promising for future nanoelectronic devices and applications. The main element of microelectronics, silicon, is composed of nuclei with zero spin and is characterized by negligible spin-orbit coupling. These properties are attractive for spin-driven applications. Recently coherent spin transport through a 350μm thick silicon wafer was demonstrated [1]. Spin-controlled qubits may be thought of as a basis for upcoming logic gates. However, the conduction band of silicon is six-fold degenerate, which is a source of potentially increased decoherence. Even in thin (001) films the two-fold degeneracy of the unprimed ladder is preserved. For spin applications this degeneracy must be removed and become larger than the spin Zeeman splitting. Experiments provide controversial insights on this issue. Electron conductivity measurements in Si-SiGe heterostructures in magnetic field reveal that the valley splitting is small [2]. At the same time, experiments on the conductance through a point contact demonstrate a splitting between equivalent valleys larger than the spin splitting [2].

We explain this controversy by considering a two-band **k·p** model for the conduction band of silicon [3,4]. The dispersion equation [5] for small shear strain ε_{xy} results in the following dispersion for the unprimed subbands n of a (001) film [6]:

$$E_n^{\pm} = \frac{\hbar^2 k_0^2}{2m_l} y_{0n}^2 + \frac{\hbar^2 (k_x^2 + k_y^2)}{2m_t} \pm \frac{y_{0n}^2 \left| D\varepsilon_{xy} - \frac{\hbar^2 k_x k_y}{M} \right|}{k_0 t \left| 1 - (\pi n / k_0 t)^2 \right|} \sin(k_o t) \qquad (1)$$

$k_0 = 0.15(2\pi)/a$ [6], t is the film thickness, $y_{0n} = \pi n/(k_0 t)$ for both subbands, D =14eV is the deformation potential for shear strain, and $1/M = 1/m_t - 1/m_0$.

Eq.(1) demonstrates that the two-fold degeneracy of the unprimed subbands can be lifted in thin films. In perpendicular magnetic fields the subband splitting is proportional to the strength of the field. Due to lateral confinement the valley splitting is enhanced in [110] oriented point contacts, while it should be weaker in a [100] point contact. Finally, the valley splitting can be controlled and made larger than the Zeeman splitting by shear strain. These results are confirmed by direct numerical solution of the Hamiltonian [3,4] in thin films, which makes silicon very attractive for spintronic applications.

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