Valley splitting and spin relaxation in strained silicon quantum wells

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Properties of semiconductors provided by the spin are of broad interest, because they have a potential for future spin-based microelectronic devices. Silicon is the main element of modern charge-based electronics. Understanding the details of the spin propagation in silicon structures is key for novel spin-based device application. However, large experimentally observed spin relaxation in electrically-gated lateral-channel silicon structures might become an obstacle for realizing spin driven devices [1], and a deeper understanding of fundamental spin relaxation mechanisms in silicon is urgently needed [3].

We investigate the surface roughness induced electron spin relaxation and the valley splitting in square silicon wells. To accurately describe the band structure in the presence of the intrinsic spin-orbit interaction a $\mathbf{k}\cdot\mathbf{p}$ Hamiltonian has been generalized to include the spin degree of freedom. The Hamiltonian is written in the vicinity of the X point along the k_z axis in the Brillouin zone. The spin-orbit term $\tau_y \otimes (k_x\sigma_x - k_y\sigma_y)$ couples the states with the opposite spin projections from the opposite valleys [2].

We solve the Hamiltonian numerically assuming that the spin is injected along the X-axis. In the presence of confinement the four-fold degeneracy of the lowest subband is partly lifted, however, the degeneracy of the eigenstates with the opposite spin projections, $\Uparrow\rangle$ and $\Downarrow\rangle$, is preserved. The degenerate states are chosen to satisfy $\langle \Uparrow |\sigma_x| \Downarrow\rangle = 0$. Shear strain makes the k_z band dispersion non-parabolic which leads to the energy splitting δE between the otherwise degenerate unprimed subbands.

Fig. 1 demonstrates the valley splitting as a function of the angle between the incident and the reflected wave. The shear strain lifts the degeneracy and makes the dependence on the angle less pronounced.

The spin relaxation matrix element mixing the up- and down-spin states from the two opposite valleys is shown in Fig. 2. In the absence of strain a sharp increase in the value of the matrix element at the angles $\pm\pi/2$ is observed. The position of these peaks correlates with the minimum of the valley splitting. While shear strain is increased the dependence of the relaxation matrix element on the angle becomes smoother. Importantly, the value of the spin relaxation matrix element is rapidly reduced with strain. Thus, applying uniaxial [110] stress suppresses spin relaxation and can be used to boost both mobility and the spin lifetime.

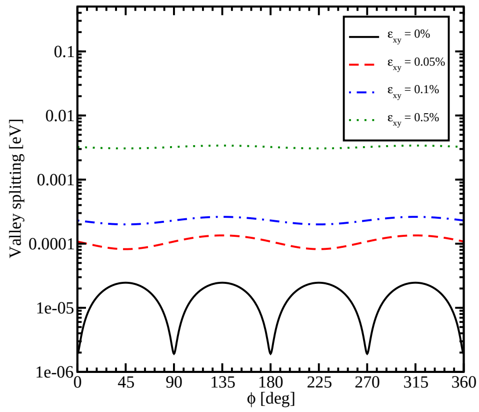

Figure 1: *Dependence of the valley splitting on the angle between the incident and the reflected wave vector for different values of the shear strain.*

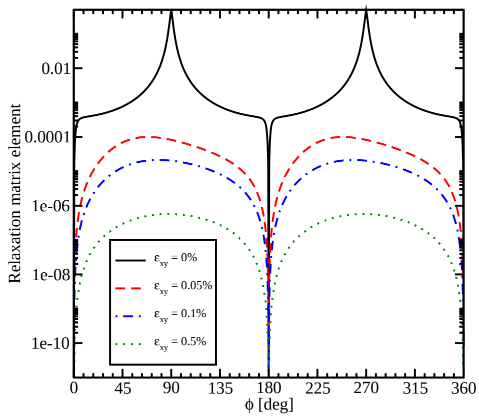

Figure 2: *The relaxation matrix element for different values of the shear strain.*

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[2] P. Li and H. Dery *Phys. Rev. Lett.* **107**, 107203 (2011).

[3] Y. Song and H. Dery, *cond-mat* 1201.6660 (2012).