# Spin Lifetime Enhancement in Strained Thin Silicon Films

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Silicon is an ideal material for spintronic applications due to a long spin lifetime in the bulk, however, a large spin relaxation in gated silicon structures was experimentally observed. Understanding the details of spin propagation in ultra-scaled MOSFETs and ways to increase the spin lifetime is urgently needed [1].

Here we investigate the spin relaxation considering two mechanisms determining the momentum relaxation: surface roughness (SR) and phonon (PH) scattering. The surface roughness scattering matrix elements are taken proportional to the square of the product of the subband wave function derivatives at the interfaces [2]. We generalize the deformation potential theory to include the phonon modes responsible for spin relaxation in confined systems. In order to find the wave functions needed to evaluate the corresponding form factors and matrix elements for spin relaxation, we employ the effective **k·p** Hamiltonian written at the *X*-point for the two relevant valleys with the spin degree of freedom properly included [1], [3].

The strain dependences of the scattering matrix elements without and with spin flip are shown in Fig.1 and Fig.2, respectively. The lowest values of the subband splitting (Fig.2) due to the valley coupling at the *X*-point are only limited by the value of the spin orbit interaction [4]. Intersubband spin relaxation matrix elements show sharp peaks at the same points (Fig.2), determining the positions of the hot spots responsible for strong electron spin relaxation in confined silicon. While the momentum relaxation is mostly determined by intrasubband scattering (Fig.3), the spin lifetime is limited by the intersubband relaxation due to elastic surface roughness and acoustic phonon scattering. For high shear strain values the hot spots are pushed to higher energies (Fig.4) away from the subband minima (inset in Fig.4). This results in an exponentially strong increase of the spin lifetime with shear strain (Fig.6). The **k·p** model [3], [4] disregards the valley coupling through the Γ-point [5]. Including this coupling results in a subband splitting already without strain [6]. The minimum splitting is now determined by this zero-strain splitting rather than spin-orbit interaction (Fig.5). This leads to the sharp and narrow spin relaxation hot spots becoming smoother and less important which reduces spin relaxation in unstrained films. However, a strong increase of the spin lifetime with strain is still preserved as shown in Fig.6. Thus, shear strain used to enhance mobility can also be used to increase spin lifetime.

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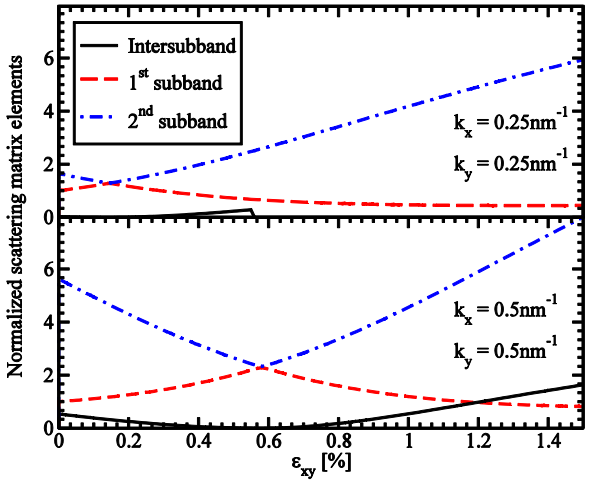


Fig.1: Dependence of the intersubband and intrasubband scattering matrix elements without spin flip normalized to the intrasubband scattering at zero strain on shear strain. Film thickness *t*=2.48nm.

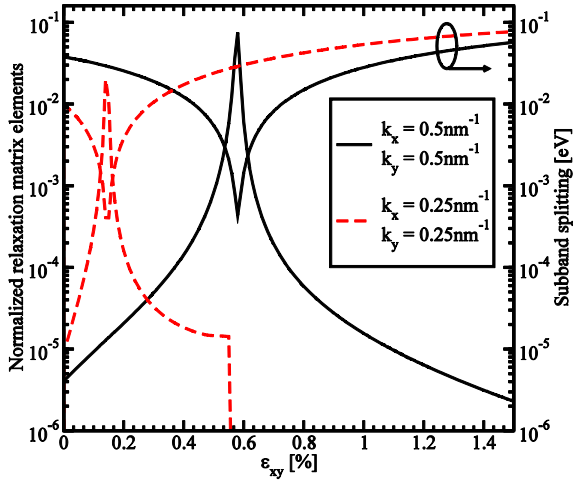


Fig.2: Dependence of the normalized intersubband relaxation spin matrix elements and splitting between two lowest subbands on shear strain.

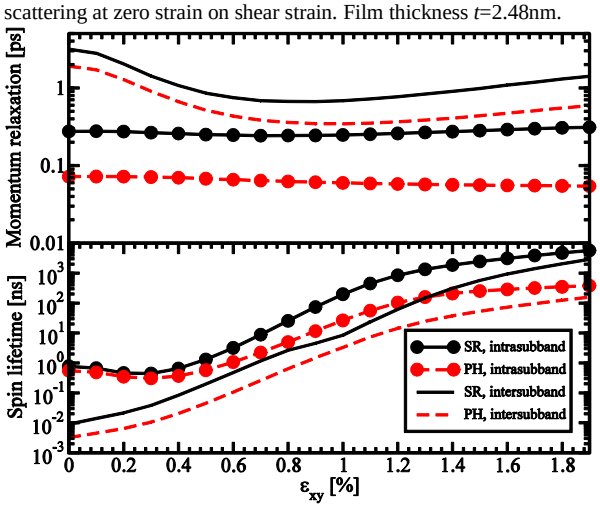


Fig.3: Intersubband and intrasubband spin lifetime and momentum relaxation as a function a function of shear strain. PH stands for acoustic phonons contribution, SR – surface roughness limited spin lifetime and momentum relaxation. *t*=2.48nm, *T*=300K.

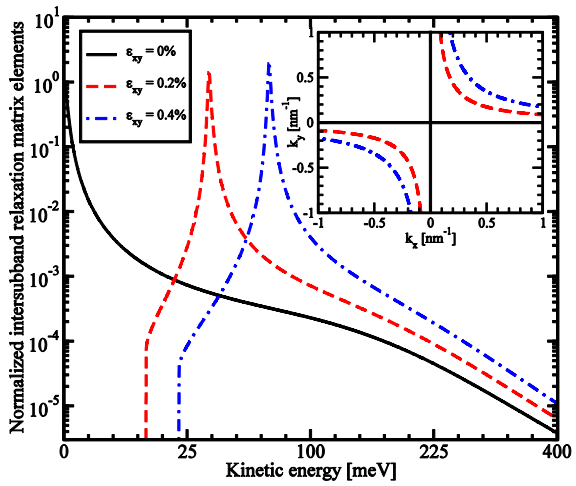


Fig.4: Normalized intersubband relaxation matrix elements as a function of the conduction electrons kinetic energy in [110] direction. The inset shows the positions of the hot spots for different values of shear strain.

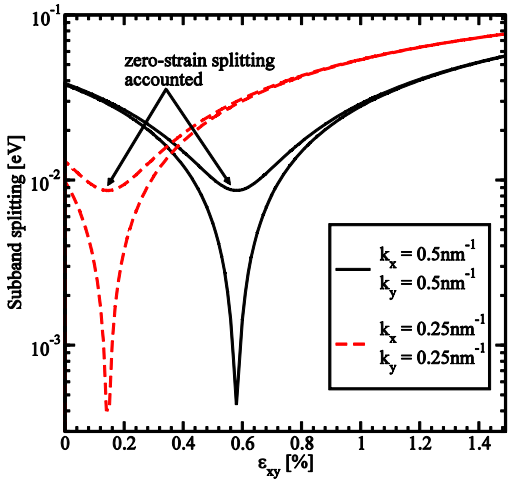


Fig.5: Splitting of the lowest subbands as a function of shear strain calculated with and without taking into account zero-strain splitting.

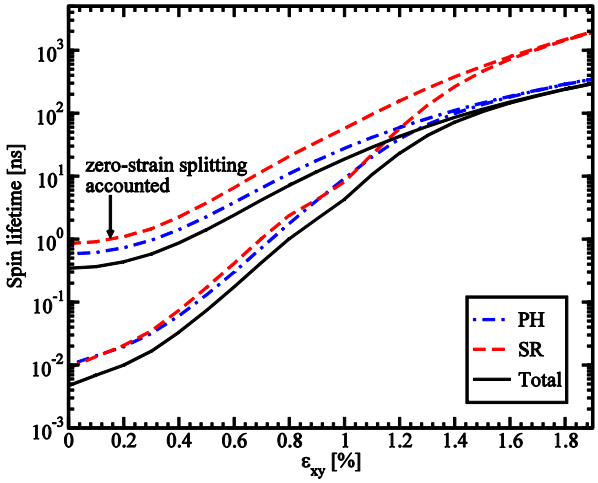


Fig.6: Dependence of the acoustic phonons (PH) and surface roughness (SR) limited spin lifetime and momentum relaxation as a function of shear strain. *t*=2.48nm, *T*=300K.