Acoustic Phonon Scattering in Free-standing Anisotropic Silicon Plates

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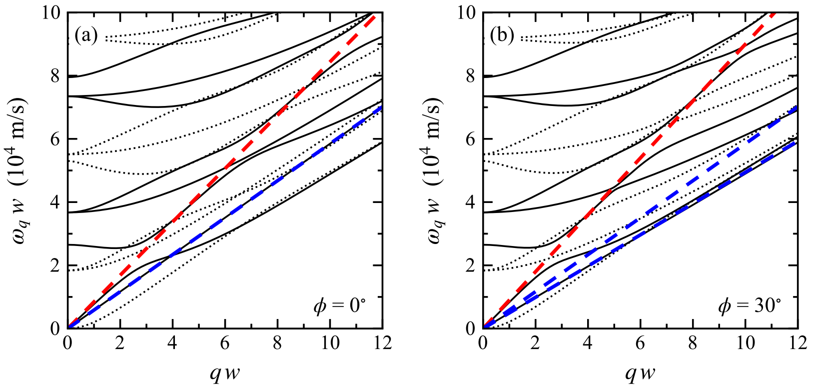
To suppress the short channel effect in ultra-small Si MOSFETs, it is necessary to introduce ultra-thin channels on the nanometer scale. In such ultra-thin channels, not only the electronic state but also the acoustic phonon mode is modulated, and the electron-phonon interaction is generally different from that assuming phonon modes in the bulk. The interaction between modulated acoustic phonons and electrons has been studied to the extent that Si is approximated as an isotropic elastic body [1, 2]. In reality, however, Si crystals are anisotropic. In this study, we investigate the effect of Si crystal anisotropy on acoustic phonon scattering in Si plates.

A free-standing Si plate with (001) surface and thickness w was considered (see the inset of Fig. 2). The acoustic phonon modes were obtained by solving the Christoffel equation. Fig. 1 shows dispersion relations; solid lines represent symmetric and dotted lines antisymmetric modes. Fig. 1(a) shows the results for the in-plane phonon wave vector, $\boldsymbol{q}$, along [100], and Fig. 1(b) for 30° off the [100] axis. The dispersion relations of (quasi-)longitudinal and (quasi-)transverse waves in bulk crystals are shown by red and blue dashed lines, respectively. Corresponding to the anisotropic sound speed of the longitudinal and transverse waves in the bulk crystal, the dispersion relation of the slab phonon is also anisotropic.

The electron mobility limited by acoustic phonon scattering was calculated within the elastic scattering and the equipartition approximations, considering only the ground subband of electrons confined in an infinite quantum well of width w. The deformation potential constants are $\Xi_\mathrm{d} + \Xi_\mathrm{u}$ in the long axis direction of the valley and Ξ_u in the short axis direction, where Ξ_d and Ξ_u are the dialational and shear deformation potential constants, respectively. The obtained mobility was converted to an effective deformation potential constant, D_eff, using the mobility formula for the isotropic deformation potential constant and the bulk phonon model. The dependence of D_eff on w is shown in Fig. 2. The slab phonon and bulk phonon results are shown by black and red lines, respectively. The solid line shows the results when crystal anisotropy is taken into account and the dashed line shows the results when isotropic elasticity is assumed. The crystal anisotropy is found to have non-negligible effects on the electron mobility.



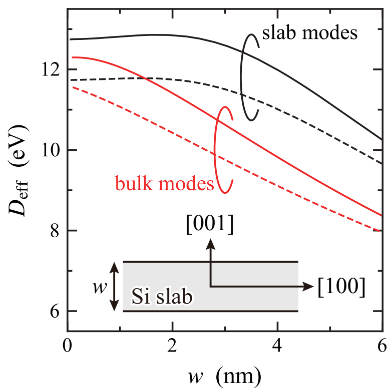


Fig. 1. [left, center]: Dispersion relation of the slab modes in a Si plate for propagation along [100] (a) and 30° off the [100] axis (b). Solid lines represent the symmetric modes and dotted lines the antisymmetric modes. Red and blue dashed lines show the bulk (quasi-)longitudinal and (quasi-)transverse modes, respectively.

Fig. 2. [right]: Effective deformation potential constant, D_eff, as a function of the slab thickness, w, for the slab (black) and the bulk modes (red). Solid lines show D_eff for the anisotropic Si plate and dashed lines for the isotropic Si model.

[1] H. Ezawa, S. Kawaji, and K. Nakamura, Jpn. J. Appl. Phys. **13**, 126 (1974).

[2] S. Uno and N. Mori, Jpn. J. Appl. Phys.**46**, L923 (2007).