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Electron Mobility in Silicon and Germanium Inversion Layers

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The perception that conventional scaling of Si MOSFETs is approaching its limits is forcing us to look at alternative ways to increase device performance, such as alternative crystal orientations, channel materials, and high-κ insulators. In this work we focus on calculating electron mobility in Si and Ge inversion layers on various crystal and channel orientations, and with high-κ insulators.

The calculation utilizes a self-consistent 1-D Schröedinger-Poisson solver with non-parabolic corrections. The mobility is then computed using the Kubo-Greenwood formula accounting for intravalley phonon scattering (described in the elastic approximation by an anisotropic model using the deformation potential obtained by Herring and Vogt [1]), intervalley phonon scattering [2], and scattering with surface roughness, accounted for following Ando's approach and by computing the screening matrix with the appropriate Green's function [3]. Scattering with gate plasmons and with interface optical phonons associated with several high-κ dielectrics are also included by solving for the dispersion of the interface modes. This is given by the solution of the secular equation associated with the dielectric function [1].

In the figures we show the electron mobility in Si and Ge inversion layers on the (100) and (1$\bar{1}$1) surfaces with the channel along the [011] and [1$\bar{1}$0] directions, respectively with an equivalent oxide thickness of 1.5 nm. As expected, Ge has a higher mobility than Si for both the phonon limited case in Fig. 1 and when surface roughness is included in Fig. 4. For Ge, the (111) surface is best at lower densities, while the (001) is better at higher densities due to surface roughness scattering. For Si, the (001) surface exhibits a higher mobility than the (111) surface, primarily due to the effect of bulk phonons. Figures 2. and 5. show the mobilities for Si and Ge including scattering with high-κ phonons. The dielectrics included are silicon dioxide and hafnium oxide. The mobility is degraded significantly by the presence of HfO_2 for both Si and Ge. Unfortunately, this is the result of the "soft phonons" responsible for the high dielectric constant itself [1]. Note that the electron mobility in Ge is depressed significantly more by scattering with the insulator phonons (also SiO_2) than Si in general. This is simply because the bulk-phonon-limited mobility in Ge is quite large and so is very sensitive to the presence of any additional scattering process. Figures 3. and 6. show the contributions of each scattering process for the (001) surface in Si and Ge respectively. Surface roughness is most important at high densities because the wavefunctions are "squeezed" tightly to the dielectric/substrate interface. Scattering with high-κ phonons has a decreasing effect at high densities, thanks to the increasing dielectric screening by the electrons in the channel.

We shall also present results related to additional surface and channel orientations, semiconductors, and high-κ dielectrics.

Acknowledgment

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References

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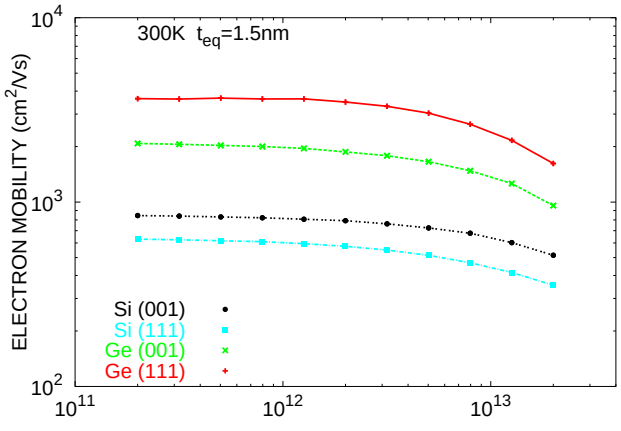

Fig. 1. Calculated phonon limited electron mobility in Si and Ge inversion layers as a function of electron sheet density.

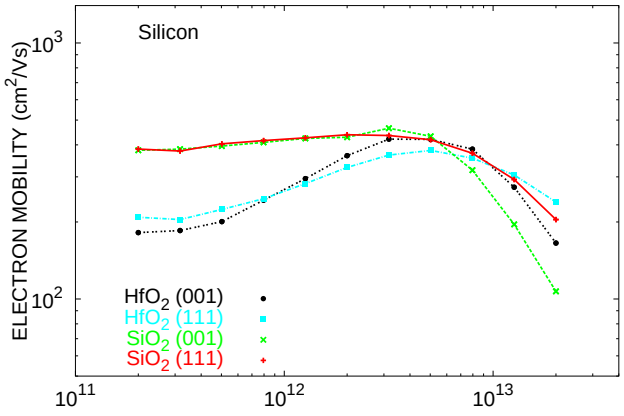

Fig. 2. Total calculated mobiltiy, including scattering with bulk phonons, surface roughness and high-κ phonons (Si only), as a function of electron sheet density.

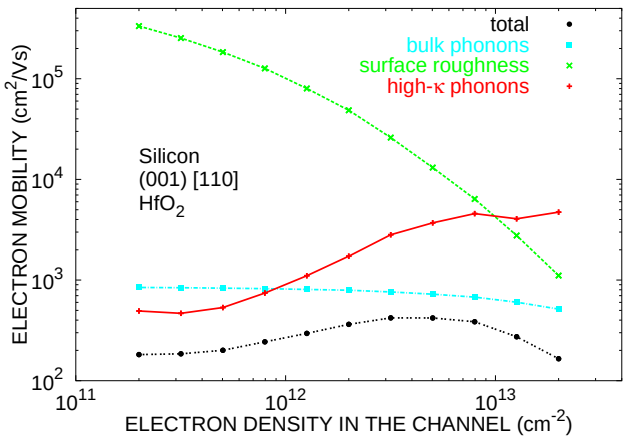

Fig. 3. Calculated contributions to the total mobility.

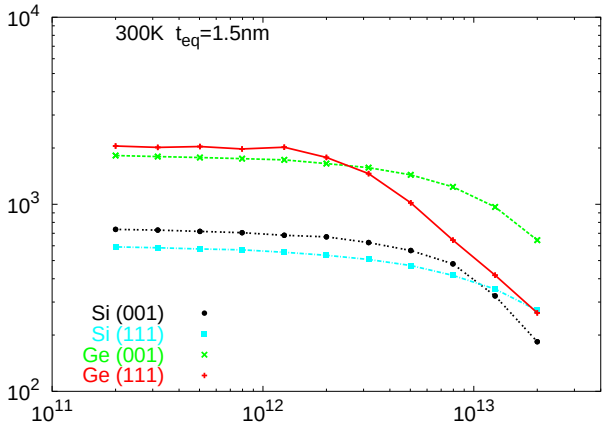

Fig. 4. As in Fig. 1, but with surface roughness included.

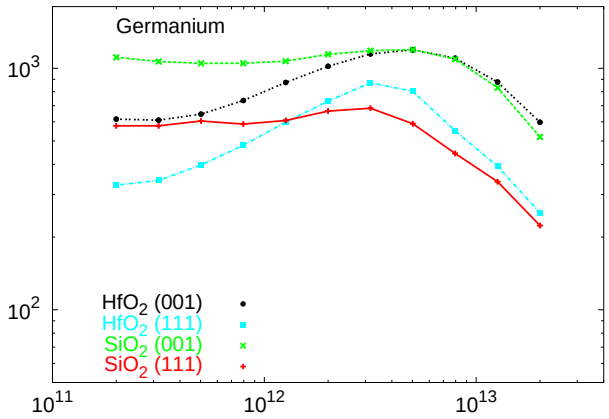

Fig. 5. As in Fig. 2, but for Ge.

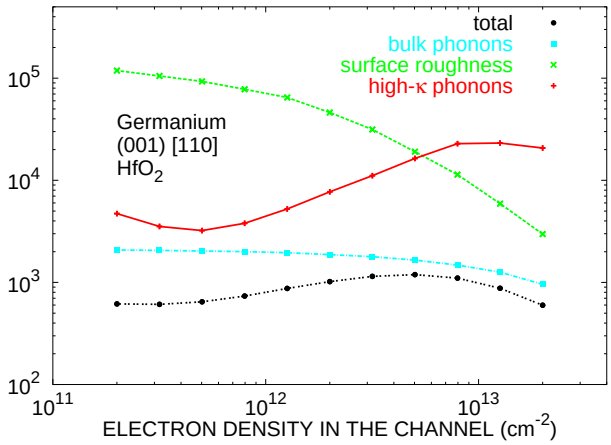

Fig. 6. As in Fig. 3, but for Ge.