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Accurate Determination of Silicon Inversion Layer Mobility by the Monte Carlo Method

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Abstract

An accurate determination of the mobility in an n-Si (100) inversion layer has been performed by the one-electron Monte-Carlo method. The calculation is based on precise models of scattering mechanisms, with special attention to coulomb scattering, for which different effects have been considered.

1. Introduction

In current MOS (Metal-Oxide-Semiconductor) technology, detailed modelling of the electron mobility in the channel of an NMOS transistor is highly desirable in order to accurately predict its behaviour in circuit applications. The Monte Carlo method is a powerful tool for calculating mobility; nevertheless, to obtain accurate results in simulation the electron transport properties, and in particular, the scattering mechanisms, need to be properly modelled.

We have performed an accurate determination of the n-Si(100) inversion layer mobility at 300 K by the one-electron Monte Carlo method. The electron mobility in silicon inversion layers had been previously determined using this procedure [1, 2], but the calculation that we present in this paper is based on more precise models of scattering mechanisms. Some details and results of our simulation are given below.

2. Method

The electron inversion layer has been treated as a two-dimensional electron gas contained in energy subbands [3]. The minima of the electric subbands arising from the equivalent minima of the silicon conduction band and the envelope functions are calculated by self- consistently solving the Schrödinger and Poisson equations [4]. Electrons can move parallel to the interface, undergoing phonon, coulomb, and surface-roughness scattering [5].

Both intervalley and intravalley phonon scattering have been considered, allowing the electron to move in the lowest six subbands. Both zero- and first-coupling order interactions have been taken into account [5, 6]. The phonon-limited mobility thus

obtained coincides with the phonon-limited mobility for the silicon bulk in the zero transverse-electric- field limit.

For Coulomb scattering, we have developed a model which, starting from previous formulations [3, 7, 8], incorporates significant improvements: it simultaneously takes into consideration the effects of i) screening by mobile carriers, ii) correlation of the oxide charges (which may be important at high concentrations), iii) distribution of the charged centres into the oxide, iv) distribution of the electrons in the inversion layer, and v) image effects caused by the difference in the dielectric constants of Si and SiO_2. In our simulation we have evaluated the local perturbation caused by the spatial fluctuations of the point-charge distributions in the potential acting on electrons in the channel. The perturbation of the potential is affected by the charges in the oxide or at the interface, by the induced electronic charge, and by the image charges of both of them. Correlation of the oxide charge distribution also affects it by decreasing the scattering, since the greater the degree of the distribution uniformity, the lower the magnitude of the fluctuations.

This theory can be used to calculate the effective mobility of the electrons in the inversion layer, and to study its dependence on different physical parameters such as: a) effective electric field (as defined in Ref.9), b) temperature, c) concentration and position of charge in the oxide, interface, and silicon, and d) correlation of the charged centres in the oxide. In this paper we show the effect of the amount and position of charge in the oxide and the influence of each scattering mechanism on the electron mobility.

3. Results

We have obtained the electron mobility in an N-type silicon inversion layer, for a sample with $N_A=10^{16}$ cm^{-3} and $N_{ox}= 0.35x10^{11}$ cm^{-2} assuming that: a) only phonon scattering exists, b) electrons are also scattered by surface-roughness, and c) all scattering mechanisms are present. Figure 1 shows the influence of the different scattering mechanisms on the mobility. It is apparent that at low fields coulomb scattering is the most important mechanism, while at high fields surface-roughness scattering is the most important.

One of the most influential limiting agents on the mobility is, according to the results in Figure 1, coulomb scattering produced by electric charges in the oxide and at the $Si\text{-}SiO_2$ interface. Although a great deal of work on modelling this mechanism has been done by other researchers [1, 2, 3, 8], there remain certain aspects requiring more work. For these reasons, we have centred our attention on this agent. In Figures 2 and 3, several curves of the effective mobility are represented versus the effective transverse field. The influence of the oxide- charge concentration is shown in Figure 2, where it can be seen that the greater the concentration, the smaller the electron mobility. These curves are in good agreement with experimental results [10]. In Figure 3, the influence of the depth of the oxide-charge is analyzed. It can be observed that the scattering of electrons by oxide charges quickly decreases when the charge is kept away from the interface. For charges placed at 100 Åor more from the interface, coulomb scattering is negligible. It is also apparent that all curves are almost superposed at high electric fields, which indicates that coulomb scattering loses its importance with respect to the other mechanisms, mainly surface roughness scattering, as the electric field grows.

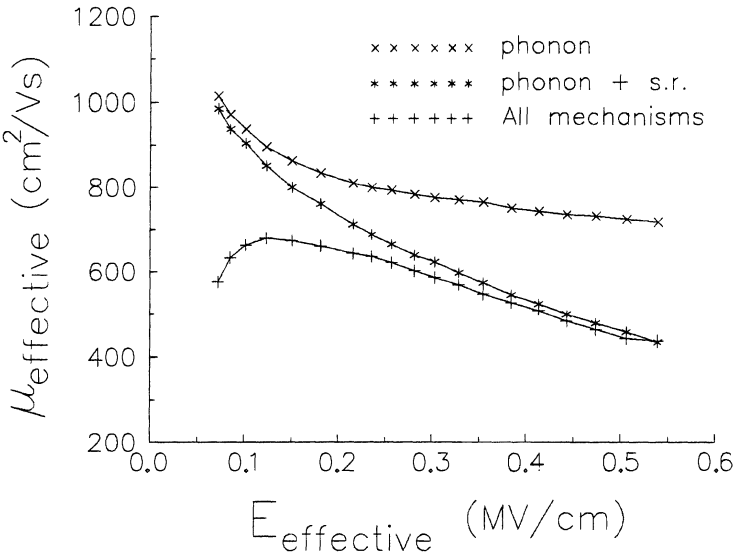

Figure 1: Plot of the effective mobility vs the effective transverse electric field showing the relative importance of the different scattering mechanisms.

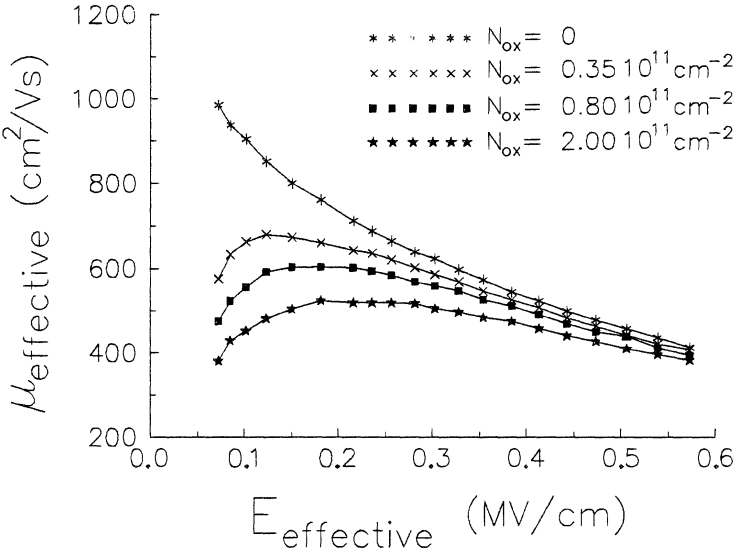

Figure 2: Plot of the effective mobility vs the effective transverse electric field for different concentrations of the oxide charge. (The position of the oxide charge is right at the interface Si-SiO_2)

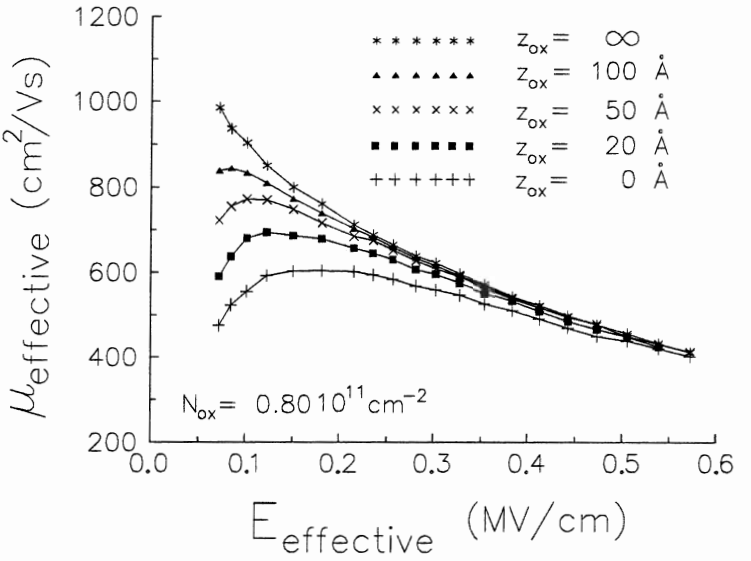

Figure 3: Plot of the effective mobility vs the effective transverse electric field for a fixed density of the oxide charge as a function of its depth inthe oxide.

4. Conclusions

In conclusion, it has been shown that by using precise models of scattering mechanisms the electron mobility in a semiconductor inversion layer can be accurately determined. Emphasis has been put on the effects of coulomb scattering and the influence of the concentration and position of the oxide- charge has been studied. The calculated curves have the same magnitude and shape as those normally obtained experimentally.

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