MONTE CARLO STUDIES OF HOT ELECTRON GENERATION IN SCALED MOSFETs

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Abstract

In this work, we report on a study of submicron MOSFET structures, performed with a full band Monte Carlo simulator. In order to obtain a systematic understanding of the hot electron effects in scaled structures, we investigate a series of devices with scaled geometry, both with constant and scaled bias.

I. INTRODUCTION

As the dimensions of integrated devices continue to shrink, investigation of hot electron effects becomes increasingly important to assess the influence of overshoot phenomena and reliability problems, like breakdown due to impact ionization, defect generation, and injection into the gate oxide. In strucures used for flash memory applications, it is important to control or even enhance the hot electron population. In order to investigate these effects in detail, it is necessary to introduce knowledge of the bandstructure in the model, because at the high electron energies involved, simple models of the band are inaccurate. Because of the massive computational resources needed [1,2], full band Monte Carlo applications for complete device structures have been possible only in relatively recent times, beginning with the development of the simulator DAMOCLES [3,4] at IBM, Yorktown Heights. In this work we report on a study of submicron MOSFET structures performed with a full band Monte Carlo simulator which includes the first two branches of the silicon conduction band.

II. MODEL

Knowledge of the bandstructure is necessary to accurately calculate the electron trajectories in real and in momentum space and to determine the density of states and therefore the scattering rates at high electron energies. Large tables store the information used to obtain the electron velocity and to relate energy and momentum for the determination of the final state after scattering. The inclusion of the band structure causes considerable numerical and memory overhead, but due to improvements in the solution techniques and to increased computational power, full band calculations are now possible on modern workstations.

In the simulator for this study, the band structure for Si is calculated using the empirical pseudopotential model of Cohen and Bergstresser [5]. All the necessary information is stored for the k points inside the irreducible wedge of the Brillouin zone and is mapped to all

the points of momentum space by using symmetry properties. The silicon model includes intravalley acoustic phonon scattering, F and G type X-X intervalley phonon scattering, X-L intervalley phonon scattering, ionized impurity scattering, and impact ionization. Ridley's statistical screening is used in the ionized impurity scattering calculation [6], and Bude's model for impact ionization is used [7]. The total scattering rate is adjusted so that at high energies, it follows the total density of states as implemented in [8].

The random flight times for the electron trajectories are generated using the vectorized ensemble constant time technique [9]. At the beginning of every iteration, the electron density in real space is evaluated using a 2-D cloud-in-cell scheme [10], and Poisson's equation is solved numerically using a simple vectorized relaxation scheme. Holes are included in the constant quasi-Fermi level approximation [3]. The boundary layer in the contacts are kept neutral by injecting the necessary number of electrons.

III. SIMULATION RESULTS

Both constant and variable bias scaling were applied to the test structure shown in Figure 1. Figure 2 shows the effect of constant bias scaling on the energy distribution at the drain/channel junction for V_{gs}= 2.5 V and V_{ds}= 3.0 V. The doping is increased and all device dimensions within the silicon are decreased by a constant factor as the device is scaled. The oxide thickness is decreased by the square root of this factor. Figure 3 shows the energy distribution when the bias is scaled with the square root of the channel length.

IV. CONCLUSION

Full band Monte Carlo is a valuable tool for studying high energy effects in scaled MOSFETs. We have demonstrated how the method can be used to generate the electron energy distribution for such devices. Analysis of the energy distribution can serve as a guideline to determine scaling rules and to assess the necessary level of statistical enhancement to study the energy tails. Future work will include the simulation of more realistic MOSFET structures and the calculation of gate and substrate currents using a stratification technique to enhance the high energy tails [11].

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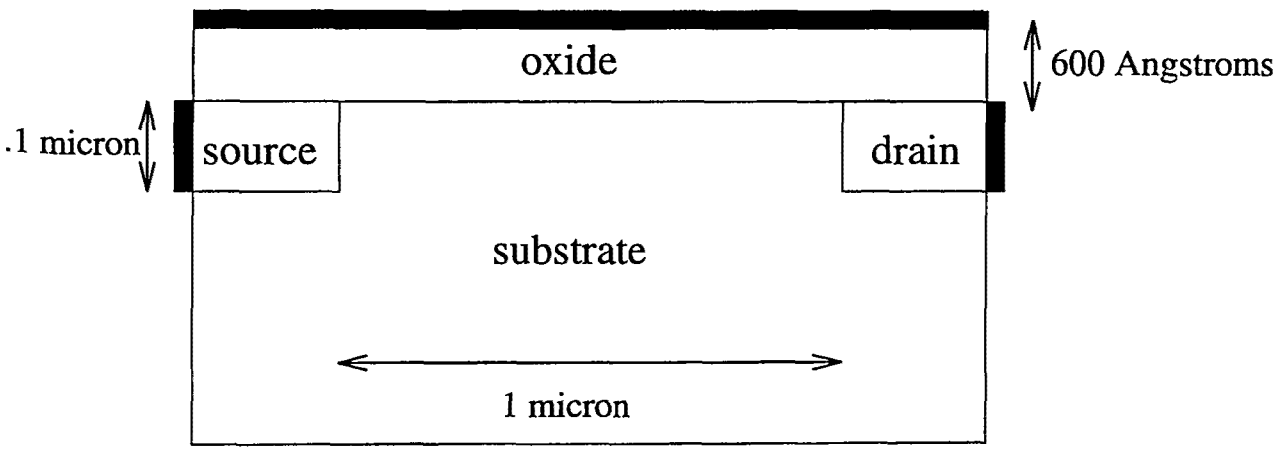

FIG 1.Schematic of device that is scaled by variable and constant bias scaling. Drain and source doping is $N_D = 10^{19} cm^{-3}$ and substrate doping is $N_A = 10^{16} cm^{-3}$. $V_{sub} = V_s = 0$ V.

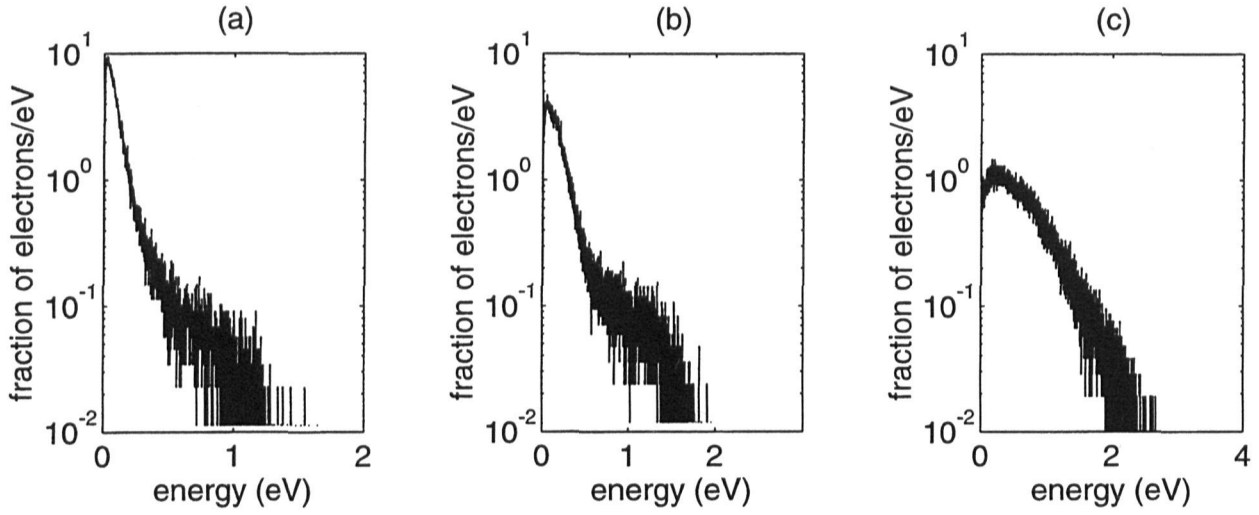

FIG 2. Energy distribution at drain/channel junction for devices with channel lengths of (a) 1μm, (b) $.5\mu$m, and (c) $.25\mu$m with constant biases of $V_{gs} = 2.5$ V and $V_{ds} = 3.0$ V

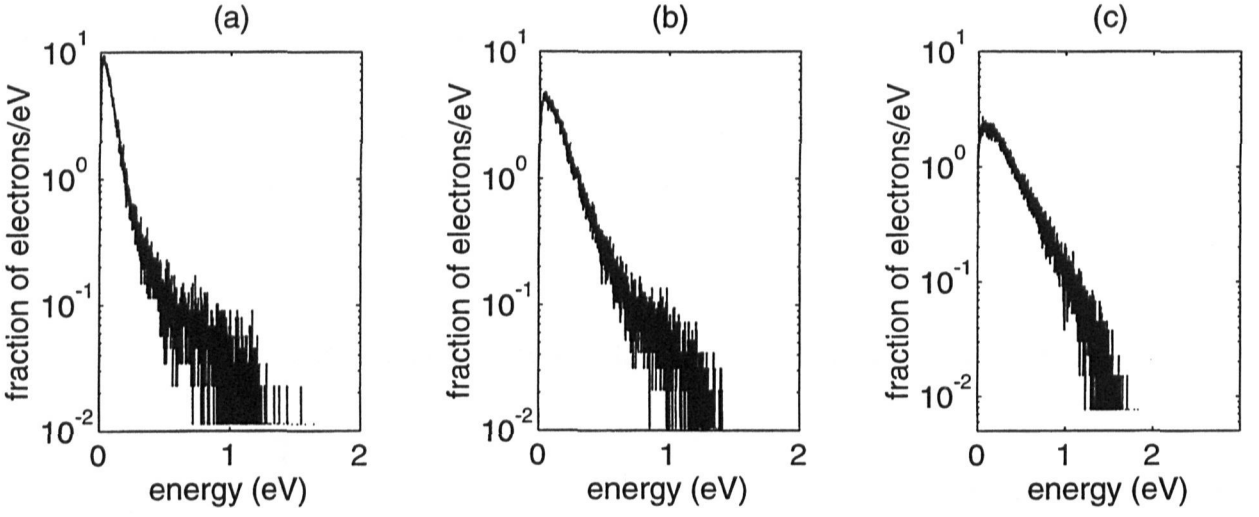

FIG 3. Energy distribution at drain/channel junction for devices with channel lengths of (a) 1μm, (b) $.5\mu$m, and (c) $.25\mu$m with scaled biases.