Monte Carlo Simulation of Electron Velocity Overshoot in DGSOI MOSFETs

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Outline

- Introduction & Aim of the presentation
- Simulation details
- Results
- Conclusions

Introduction

Velocity Overshoot (VO) is an effect observed in very short channel devices.

- Experimentally observed as an increase in current drive and transconductance.
- Transit time is reduced due to lower L_{ch} and also because $v > v_{sat}$.
- Could VO improve the performance of very short channel devices?

Study of VO effect

- Apply low E_{long} for $t < t_0$ and high E_{long} at $t=t_0$. Electric field step $\rightarrow$ Electron velocity overshoot for a time $t < \tau_e$ (energy relaxation time).
- The electron gas is not in equilibrium with the lattice $\rightarrow$ Insufficient phonon scattering events.
- Electrons are accelerated $v > v_{sat}$ until the electron energy reaches its new steady-state.

Continuous improvement of device performance

New device structures → Double Gate SOI

- Control of SCEs by device geometry compared to a bulk MOSFET where SCEs are controlled by doping. Thin T_{Si} leads to a strong coupling of the gate potential with the channel potential.
- Reduction of parasitic capacitances.
- Increased radiation tolerance and increased mobility (volume inversion).

Goal of the work

Confinement of electrons in a very thin silicon film produces important differences compared with bulk MOSFETs:

1. Subband modulation
2. Increase in the phonon scattering rate

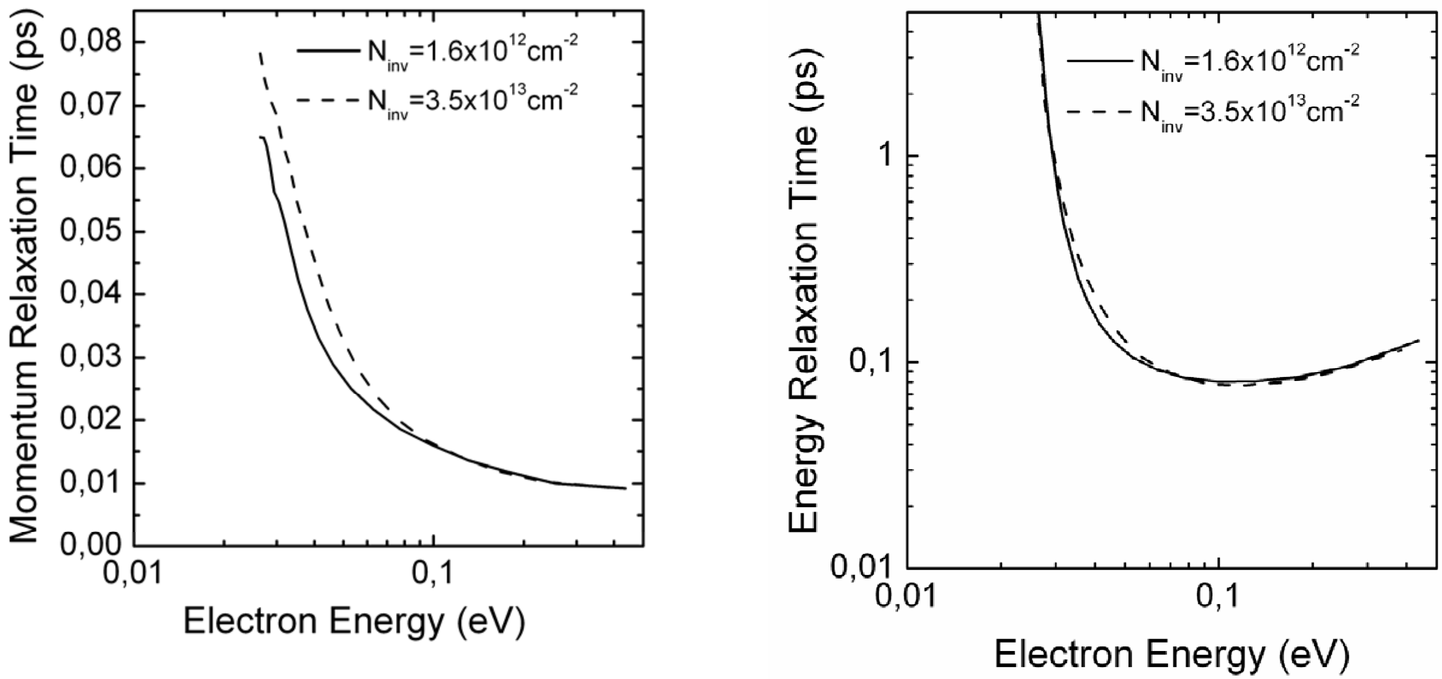
Try to study the influence of these phenomena on the VO of the electrons and its dependence with technological parameters (T_{Si}, N_{inv})

Simulation Details

- Structure considered: DGSOI transistor with N^+ poly gates, undoped silicon layer $1.5\text{nm} \leq T_{Si} \leq 20\text{nm}, T_{ox} = 2\text{nm}$
- Self consistent solution of Poisson & Schrödinger equations.
- Nonparabolic band model $\alpha=0.5\text{eV}^{-1}$.
- One-electron Monte Carlo simulator.
- Phonon, surface-roughness and Coulomb scattering mechanisms were included.

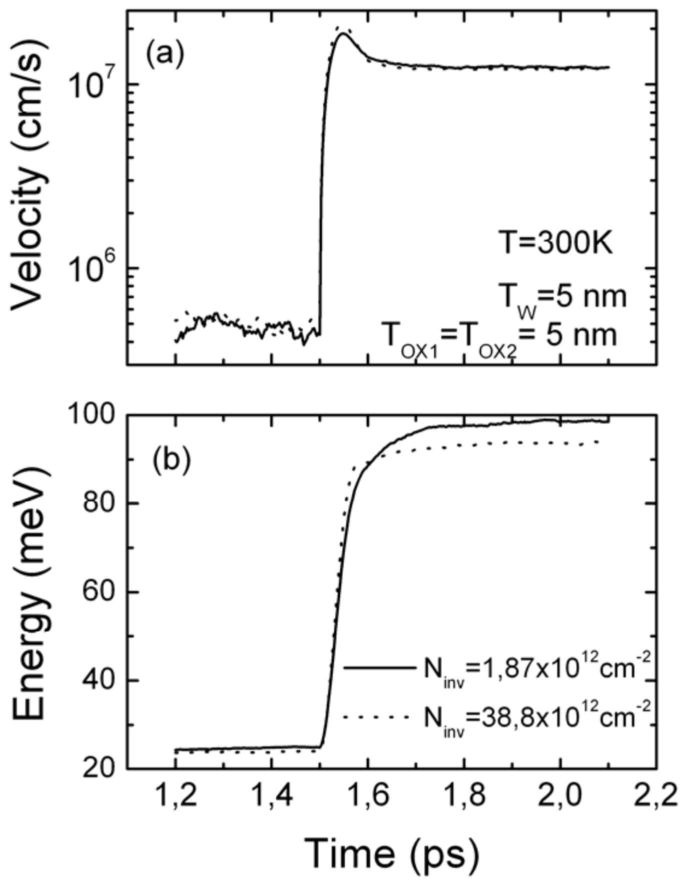
Momentum and Energy Relaxation Time

DGSOI with $T_{Si} = 5nm$, $T_{ox1} = T_{ox2} = 2nm$, T=300K



Energy and momentum relaxation times show different values → Velocity Overshoot

Evolution of the energy and velocity of a distribution of electrons after the sudden application of a high longitudinal field:



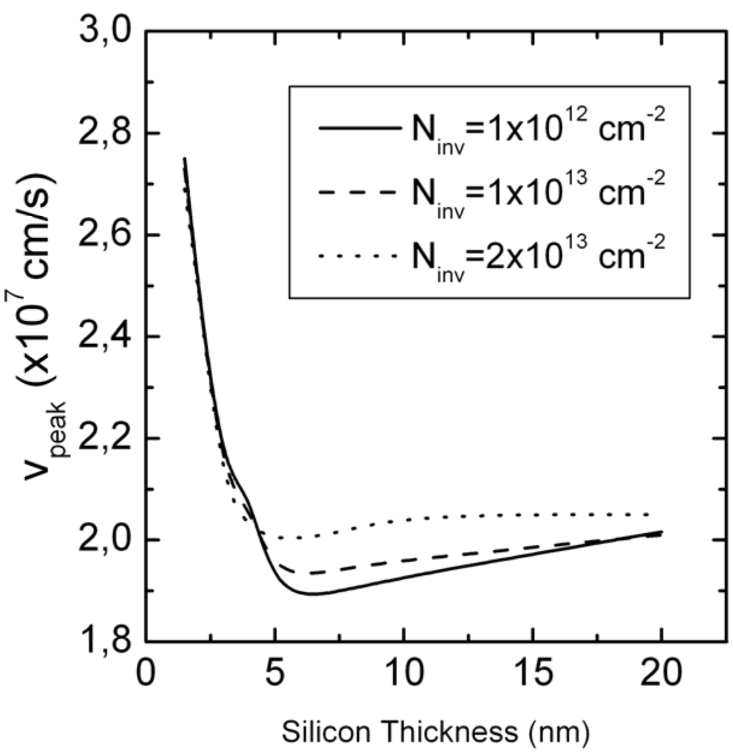
$t < 1.5ps \quad E = 10^3$ V/cm
$t > 1.5ps \quad E = 10^5$ V/cm

Transient velocity overshoot e^- velocity surpasses the final steady-state value, reaches a maximum and decreases.

$$\tau_{VO} \approx 0.1ps \;\rightarrow\; 0.1ps \times 10^7 \frac{cm}{s} = 10nm$$

Electron energy slowly tends to the final value.

Evolution of the velocity overshoot peak with the silicon thickness (1.5nm < T_{Si} < 20nm) evaluated for different values of N_{inv} .



Higher values for T_{Si} < 5nm

Minimum v_{peak} around 5nm

Slight increase for T_{Si} > 5nm

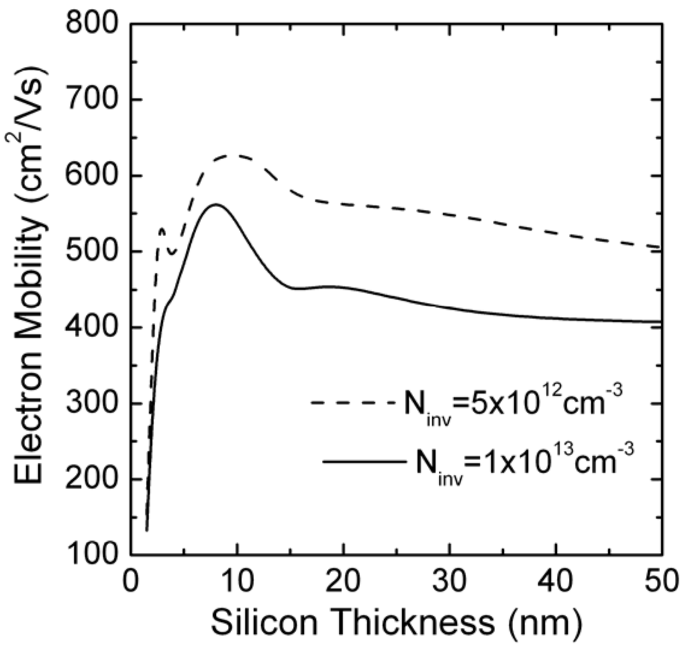
Two opposite effects influence on the electron transport in DGSOI for very thin silicon thickness:

1.- Subband modulation produces a decrease in the conduction effective mass.

2.- Greater confinement produces an increase in the phonon scattering rate.

Subband modulation effects favor electron transport while the phonon scattering increase impedes it.

Electron mobility in a DGSOI transistor as a function of the silicon thickness

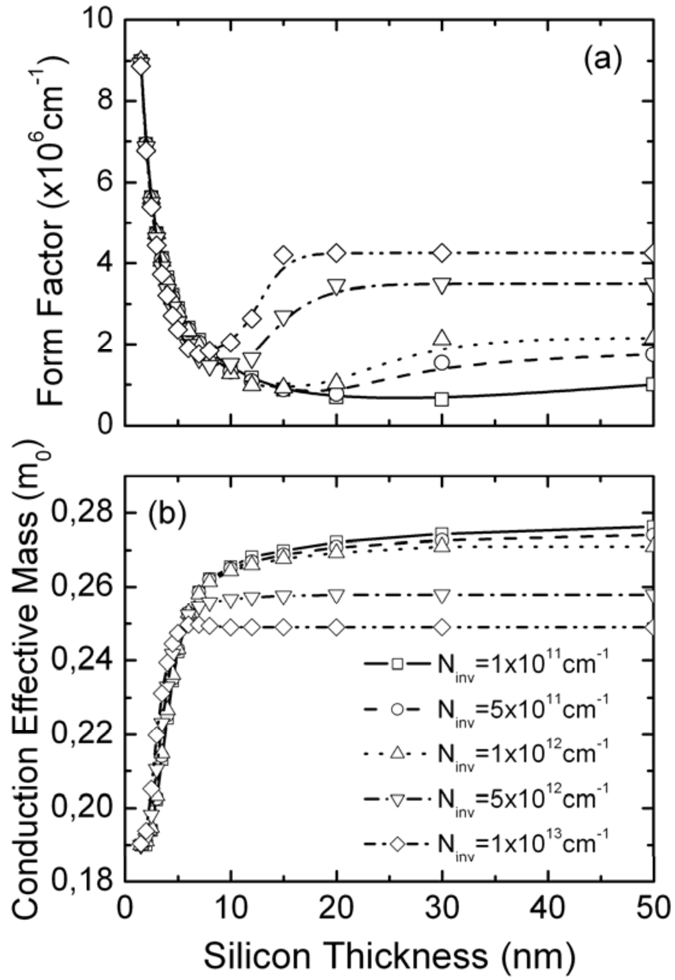


T_{Si} > 20nm
Two separate inversion layers

5nm < T_{Si} < 20nm
Interaction between inversion layers
Subband structure and wavefunctions strongly modified

T_{Si} < 5nm
Strong increase in the phonon scattering rate

Taking into account mobility considerations T_{Si} < 5nm should not be used



Form factor for the ground subband in the DGSOI inversion layer as a function of T_{Si} for different values of the electron inversion density.

⇓

High phonon scattering rate for T_{Si} < 5nm

Average conduction effective mass for electrons in a the DGSOI inversion layer as a function of T_{Si} for different values of N_{inv}.

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m_{eff} reduction for T_{Si} < 5nm

Conclusions

• Behavior of μ_n for T_{Si} < 5nm is mainly controlled by the phonon scattering rate

• The VOP for T_{Si} < 5nm is controlled by the average conduction effective mass

Could VO improve the DGSOI performance?
Calculation of I-V curves → Ensemble quantum Monte Carlo simulator which includes all the effects previously mentioned.