Influence of ballistic effects in ultra-small MOSFETs

J. Saint Martin, V. Aubry-Fortuna, A. Bournel, P. Dollfus, S. Galdin, C. Chassat
IEF, UMR CNRS 8622, Université Paris Sud, 91405 Orsay cedex France
email: stmartin@ief.u-psud.fr website: http://www.u-psud.fr/ief

In nanotransistors where the channel length is comparable to the electron mean free path, ballistic transport is of great importance regarding the device performance [1]. In this context, Double Gate MOSFET (DGMOS) with effective channel length and Silicon thickness equal to 25 nm and 10 nm, respectively, has been studied using semi-classical Monte Carlo simulations to investigate the influence of ballistic electrons.

The intrinsic ballisticity B_{int} is defined as the percentage of ballistic electrons, i.e. which have flown from Source-end to Drain-end of the channel without any scattering events [2]. The voltages dependence of B_{int} has been investigated and is shown in figure 1. As expected, B_{int} decreases as Gate Source Voltage V_{GS} increases, which results from enhancement of roughness scattering at high V_{GS}. However the V_{DS} dependence of B_{int} is more astonishing: the rise of V_{DS} induces the decay of B_{int}. This evolution seems to be due to drain-induced electrons heating: the effect of scattering rate enhancement on the number of scattering events, mostly in the second half of the channel (not shown), is stronger than the effect of reduction of carrier transit time. At low V_{DS}, the scattering number remains very weak, i.e. even in the "linear" regime (for V_{DS} below 0.2 V at $V_{GS} = 0.7$ V) the electronic transport looks like quasi-ballistic. The last feature raises an important question about the relevancy of the notion of long channel effective mobility μ_{eff} which is widely used in device engineering: is it a good parameter to predict the performance of ultra small channel devices?

As electrons with transverse mass are the lightest and thus the fastest electrons, they enhance μ_{eff} and provide the most important contribution to the ballistic population. So, to analyze further more the links between μ_{eff}, B_{int} and the on-current I_{on}, we have investigated strained Si devices where the number of electrons with transverse mass is controlled by strain.

Consequently, we have studied a 18 nm-long strained Silicon SGMOS grown on a $Si_{1-x}Ge_x$ buffer. In these devices, parameters μ_{eff} and B_{int} can be easily tuned by modifying the percentage of Germanium x in $Si_{1-x}Ge_x$ buffer. The figure 2, which presents velocity spectrum at the drain-end for x = 20%, indicates clearly that only transverse mass electrons are ballistic in strained Si, contrary to the case of unstrained channel [2].

The I_{on} dependences of B_{int} and μ_{eff} are plotted in figure 3 for x varying from 0 to 20%. We observe that I_{on} varies linearly with B_{int} whereas μ_{eff}, evaluated from Monte Carlo simulation of long channel devices, saturates under high strain, i.e. for high I_{on}. It suggests that B_{int} is a more relevant parameter than μ_{eff} to characterize the performance of ultra-small devices.

A detailed investigation of ballistic effects and their influence on device characteristics will be presented at the conference for various MOS architectures (single gate, double gate, strained and unstrained Si...).

[1] M. Lundstrom and Z. Ren, IEEE Trans. Electron. Dev., vol. 49, pp. 133-141, 2002

[2] J. Saint Martin, A. Bournel, P. Dollfus., to be published in IEEE Trans. Electron Dev., July 2004

A full journal publication of this work will be published in the Journal of Computational Electronics.

0-7803-8649-3/04/$20.00 Copyright 2004 IEEE

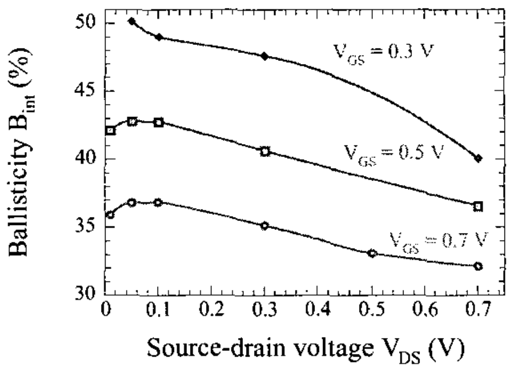

Figure 1: B_{int} as a function of V_{DS} for different V_{GS} in 25nm-long DGMOS

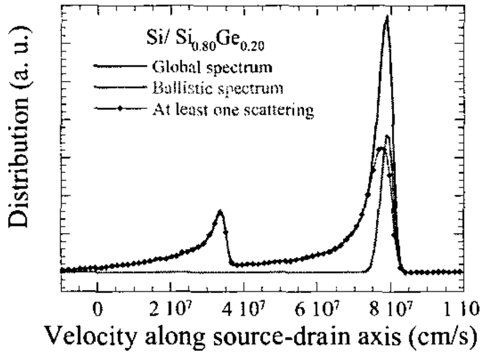

Figure 2: Velocity distributions at the drain end of strained Si SGMOS grown on $Si_{0.80}Ge_{0.20}$

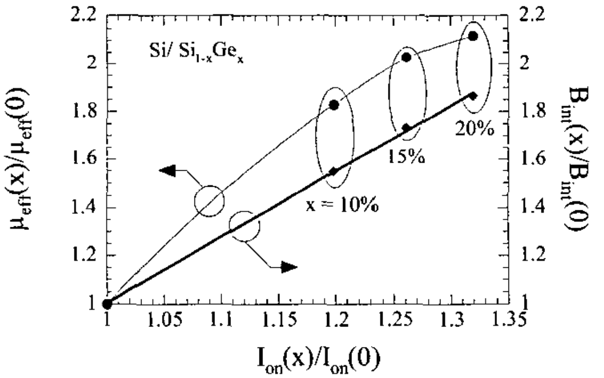

Figure 3: Normalized B_{int} and μ_{eff} as a function of normalized I_{on} for different 18 nm-long strained Si SGMOS grown on $Si_{1-x}Ge_x$ (x = 0, 10, 15 and 20%)

A full journal publication of this work will be published in the Journal of Computational Electronics.