A SELF-CONSISTENT QUANTUM MECHANICAL SIMULATION OF P-CHANNEL STRAINED SiGe MOSFETs

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The semiconductor industry's relentless effort to extract enhanced performance from MOS transistors has led to greater device functionality at lower costs. For over three decades, this trend has been sustained mainly by scaling the device critical dimensions. Sometime within the next five years, however, traditional CMOS technology is expected to reach limits of scaling. As channel lengths shrink below 50 nm [1], complex channel profiles are required to achieve desired threshold voltages and to alleviate the short-channel effects [2]. New transistors — particularly double-gate, FinFETs and ultrathin-body (UTB) MOSFETs offer paths to further scaling, perhaps to the end of the 2003 International Technology Roadmap for Semiconductors (ITRS) [3]. *Another alternative is offered by strained material systems*, such as surface-channel strained-Si or buried-channel strained SiGe devices, whose fabrication process can easily be integrated into conventional CMOS processing.

Strained-SiGe buried-channel MOSFETs, schematically shown in Fig. 1, provide enhanced hole mobilities because of two reasons: first, the compressive strain reduces the in-plane hole effective masses and second, the buried layer causes hole confinement (due to the valence band offsets) and so surface roughness at the Si-$Si0_2$ interface is not a big factor. Alloy scattering in this buried channel dominates instead [4,5]. The enhanced effective mobilities of a quasi 2D hole gas are shown in Fig. 2 [5]. These results have been obtained with our in-house device simulator.

In this work, we investigate hole current enhancement in a 25 nm strained SiGe p-channel MOSFET using a fully self-consistent Schrödinger − Monte Carlo – Poisson transport model. The 2D carrier eigenstates are constructed from the solution of the 1D Schrödinger equation along the depth direction, with each slice along the length direction (see Fig. 1) having different set of 1D eigenstates. In most previous approaches, the carriers in the source and drain regions have been treated as 3D particles which requires special treatment of the carriers at the 3D→2D interface in order to conserve carrier energy and momentum. In this work, to avoid this complication and to minimize the errors that are introduced with this approach, we have extended the quantum simulation domain into the source and drain regions so that no special treatment is needed at the channel boundaries. Furthermore, von Neumann boundary conditions are employed to obtain proper charge density in the ohmic contacts and Dirichlet boundary conditions have been used in the channel region of the device. The output characteristics of a conventional Si p-channel MOSFET and a strained SiGe p-channel MOSFET are shown in Figures 3 and 4, respectively. It is seen that there is a peak current enhancement of about 60% due to the bandstructure modification of the hole effective mass in the strained SiGe device. Also note that there is considerable DIBL effect in both device structures and this issue is currently being investigated. Research is also underway to move away from the effective mass picture, by performing first-principles band-structure calculation for the strained SiGe heterostructure. We utilize DFT and tight binding model to calculate the 2D eigenstates in the structure that will naturally incorporate the alloy disorder scattering. The results of this work will also be presented at the conference.

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

References:

[1] SIA Technology Roadmap for Semiconductors, 2003 (http://public.itrs.net/).

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[3] P. M. Zeitzoff and H. R. Huff, "Non-Classical CMOS: the "Ultimate" MOSFET Device", EE Times, August 27, 2003.

[4] P.M. Garone, V. Venkataraman, and J.C. Sturm, IEEE Electron Device Lett., Vol. 13, 56 (1992).

[5] S. Krishnan and D. Vasileska, "Self-consistent subband structure and mobility of two dimensional holes in strained SiGe MOSFETs", Journal of Computational Electronics, Vol. 2, 443 (2003).

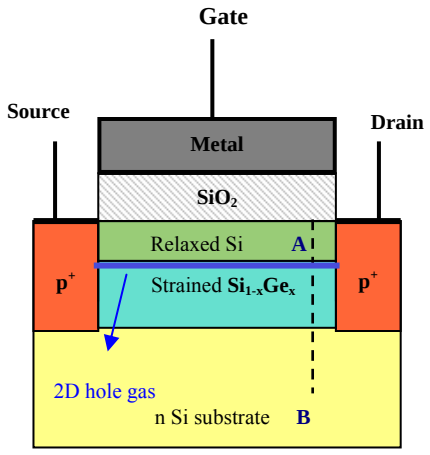

Fig.1. Simulated Device Structure. The quantization of hole states is calculated along the dashed line AB.

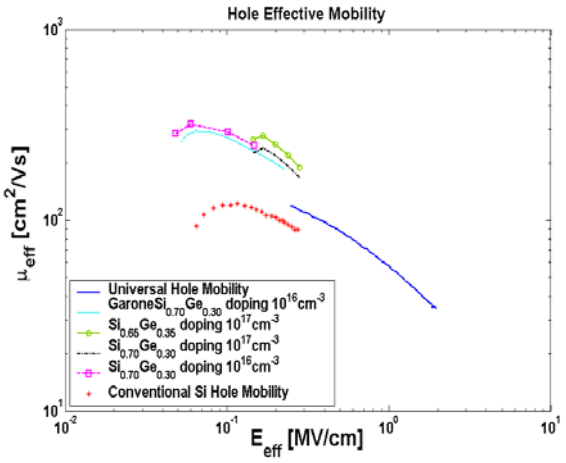

Fig.2. Hole mobility vs. effective electric field. Notice the excellent agreement with experimental data for various substrate doping

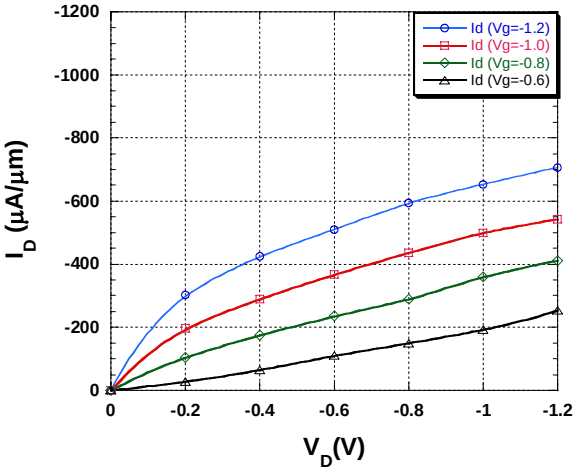

Fig.3. Output Characteristics of a conventional p-channel Si MOSFET. The gate length is 25 nm.

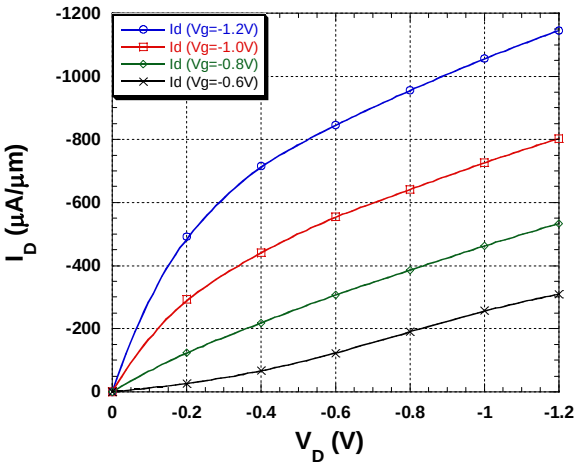

Fig.4. Output Characteristics of a strained-SiGe p-channel MOSFET. The gate length is 25 nm.

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