A Velocity-Overshoot Subthreshold Current Model for Deep-Submicrometer MOSFET Devices

Wensheng Qian Xing Zhou Yuwen Wang Khee Yong Lim

School of Electrical & Electronic Engineering, Nanyang Technological University,
Nanyang Avenue, Singapore 639798.
Tel.: (65)7905129 Email: ewsqian@ntu.edu.sg

Abstract-Advances in VLSI fabrication technology drive the device toward deep-submicrometer dimensions. For many kinds of special effect such as velocity overshoot effect, short channel effect, drain-induced barrier lowering etc., submicrometer MOSFETs exhibit different characteristics compared to conventional ones. Thus special models have to be used to simulate the performance of submicrometer devices. Subthreshold performance of MOSFETs is quite important for low-voltage, low-power applications. In the subthreshould region, the diffusion current is usually expected to be dominant, because the depletion charge is much larger than the inversion charge. But for submicrometer MOSFETs, the contribution of the drift current to the total current can not be neglected because of the stronger lateral electrical field in shorter channel devices.

In this paper, a new theoretical approach to submicrometer MOSFET subthreshold current modeling is presented. This model starts from mobility modeling. The channel lateral electric field of deep-submicrometer MOSFET is no longer homogeneous. If the field increases within a mean free path, the average electron energy is lower than the energy in uniform electric field, and the lower average energy results in higher drift velocity. An effective mobility including carrier velocity overshoot is used to replace the electric field mobility in the conventional model. Accurate channel surface potential model is essential for drain current simulation because it is no longer a constant in short channel. Gauss′s Law is adopted to calculate the surface potential, partial voltage drop of the drain bias and the quasi-fermi level at every point in the channel. The weak inversion charge model is developed by solving Poisson equation involving the expressions of the surface potential and quasi-Fermi level. According to the channel potential, the lateral electric field distribution and the position of carrier velocity saturation are obtained. The diffusion and drift subthreshold currents are calculated, respectively, in the range between the source and the velocity saturation point. Because the effect of channel length modulation is apparent in deep-submicrometer devices, the effective channel length is applied to replace of the channel length in the model. The simulation results are compared with MEDICI for verification.

From the calculation results of different channel surface potential (Fig. 1), it is apparent that the surface potential is almost constant in long channel, but has a large variation in short channel. This shows that it is necessary to use the local surface potential for deep-submicrometer device simulation. Figs. 2(a, b) show the dependence of the calculated drain current on gate voltage at V_{DS}=2V, 4V, and comparison with MEDICI simulation. The calculated results agree well with MEDICI in subthreshould region (V_{th}=0.37V) at different V_{DS}. To clarify the carrier velocity overshoot effect on device subthreshold characteristic, we compare the calculated values of drain current with that of no overshoot at V_{DS}=2V and 4V in Fig.4 (a, b). At V_{DS}=2V, the difference between the drain currents with and without overshoot is quite small. But when V_{DS} becomes larger, overshoot effect is very obvious. As the results of the simulation, high lateral electric field in device channel is the basic factor of overshoot effect, and both of short channel and high drain bias are the conditions under which this effect appears.

This is a physics-based analytical subthreshold current model for deep-submicron devices at high drain bias.

Topic: Process, Device and Circuit Simulation (Special Session: Compact Modeling for Deep-Submicron Technology Development and Device/Circuit Design)

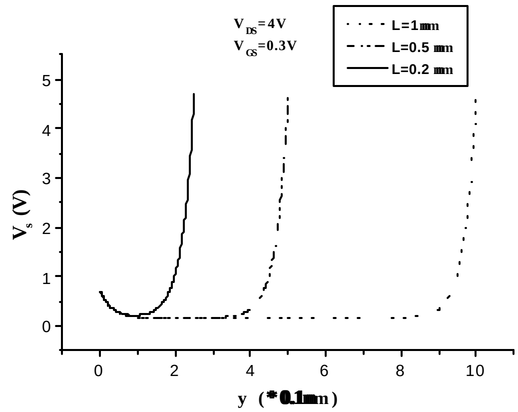
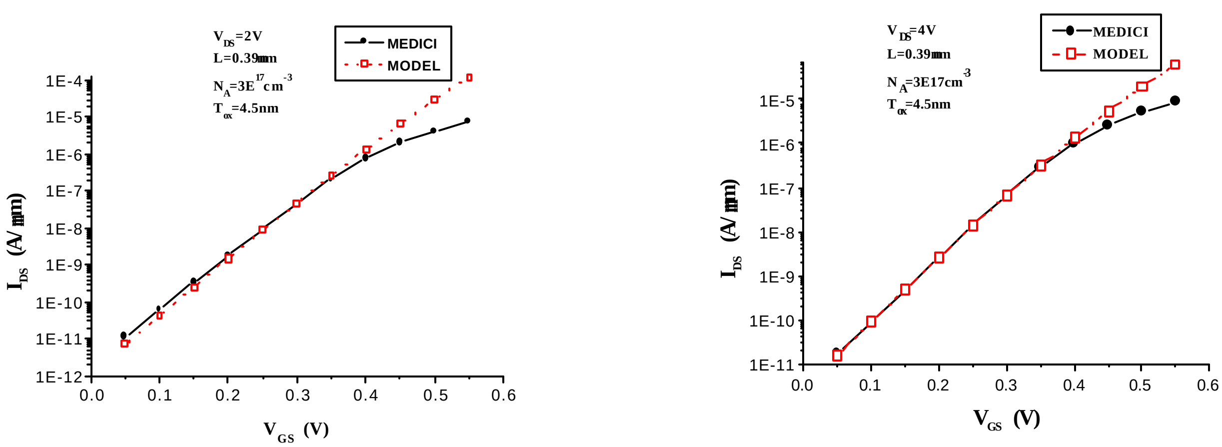


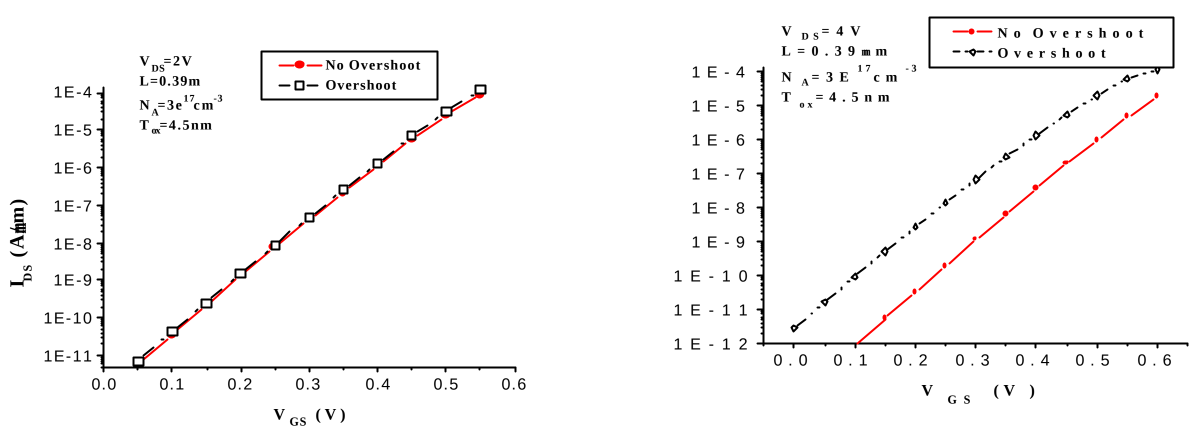
Fig.1. Channel surface potential Vs of different channel length as a function of channel position y



(a) **(b)**

Fig.2. Calculated and MEDICI simulated drain current I_{DS} as a function of gate voltage V_{GS}

(a): V_{DS}=2V (b): V_{DS}=4V



(a) **(b)**

Fig.3. Calculated drain current I_{DS} as a function of gate voltage V_{GS}

(a): V_{DS}=2V (b): V_{DS}=4V