Source- Drain-C(V)-behaviour of short channel LDD-MOSFETs

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Abstract

Two basic capacitance effects can be distinguished: the space-charge capacitances and the one of the overlap regions. These effects have a substantial influence on the total capacitance behaviour of the transistor if the channel is shorter than $0.25\mu m$. A model has been developed and incorporated into the existing BSIM3v3.1 compact model for circuit simulation.

1. Introduction

With decreasing channel length the capacitances of the drain and source regions become a substantial factor to the total C(V)-behaviour of short channel LDD-MOSFETs. In this paper we report therefore about the modelling of the non-linear space charge and overlap capacitances of those regions. The validity of the model is compared with device simulations and measurements.

In order to describe the interesting effects a typical LDD-MOSFET (fig. 1) with its doping and surface potential is used for demonstration. Depending on the gate voltage different surface potential ψ_S exist. Accordingly the overlap region (n^-)is able to collect electrons and holes as the device simulations (fig. 2) indicates. Those charges represent the non-linear overlap capacitance $C_{Ov}(V)$. The other capacitance is the one of the space charge layer $C_{SC}(V)$. The charge distribution is depict in fig. 3. The C(V)-behaviour of the inner MOS-transistor (fig. 1) is used unchanged as defined in the BSIM3v3.1 [1] description as well as the fringing effect represented by C_{fr}.

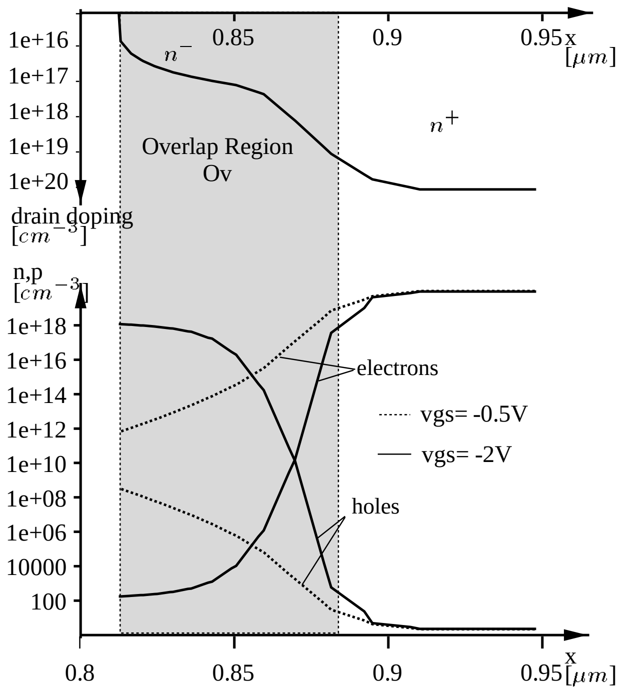

Figure 2. Electron and hole distributions in the overlap region resulting from a device simulation

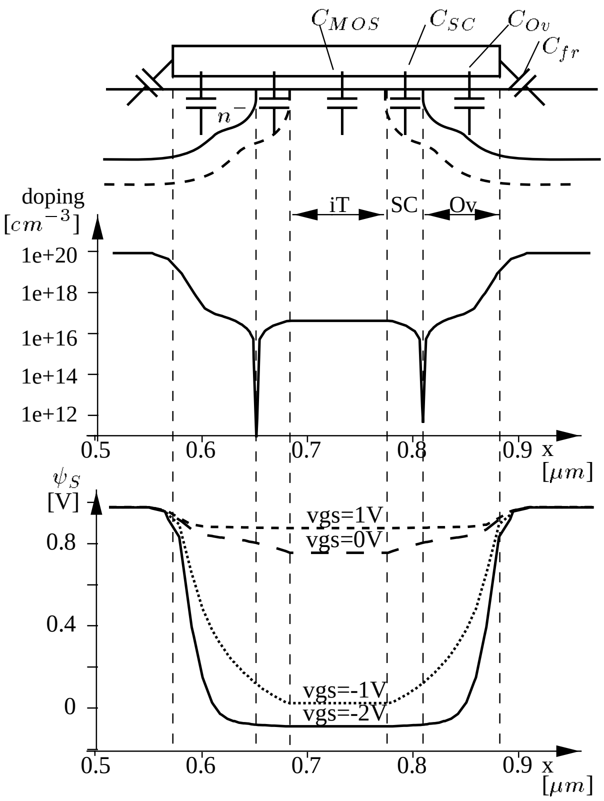

Figure 1. The transistor's regions for C(V)-description.

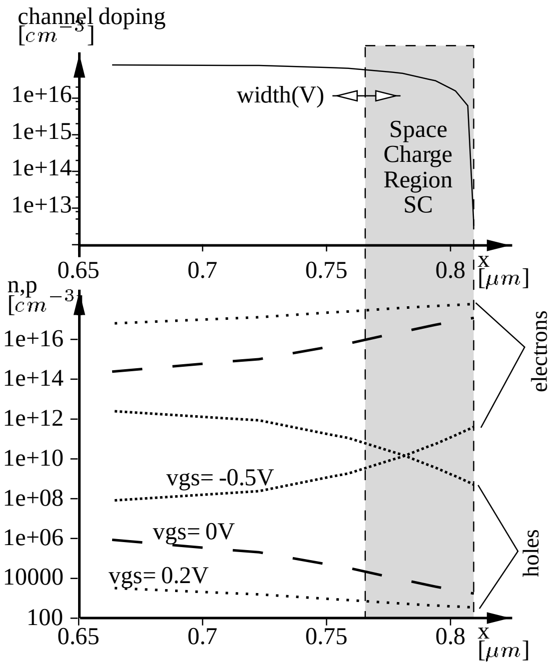

Figure 3. Electron and hole distributions in the space charge region resulting from a device simulation

2. Theory

To describe these effects accurately the 2-dimensional Poisson's equations has to be solved. To simplify the description the 2D-problem has been splitted into two 1D-problems: First Poisson's equations for the non-gated diodes source-bulk and drain-bulk has been solved using the depletion approximation. Using this solution of the 1D-Poisson's equation as boundary condition for the vertical problem the charge distribution can be determined (Appendix A).

3. Simulation and Discussion

The doping profile is approximated by a step function profile. This simplifies the solution of Poisson's equation. In this case a Gaussian profile with just two parameters was used and for each step the potential ψ, the body effect coefficient γ, the flat band voltage V_{FB} and the fermi level ϕ_f determined. These individual results are used to derive the surface potential ψ_S and the charge for each doping step and location respectively. The results for negative gate voltages are shown in fig. 4 for the drain side. Applying a negative gate voltage the overlap region is depleted. The positive ions N_D^+ result in a positive depletion charge $\sigma_{Ov}(Drain)$ belonging to the drain charge. Enhancing the negative gate voltages holes flow from the bulk into the overlap region and build an inversion layer. Its charge $\sigma_{Ov}(Bulk)$ can be considered to be a bulk charge. In the space charge regions holes are accumulated resulting in a bulk charge $\sigma_{SC}(Bulk)$ also. In fig. 4 the charge distributions $\sigma_{Ov}(Drain)$ and $\sigma_{Ov}(Bulk)$ are also shown. Fig. 5 shows the case for positive gate voltages. The charge distributions are $\sigma_{SC}(Drain)$ and $\sigma_{SC}(Bulk)$ analogous to $\sigma_{Ov}(Bulk)$ and $\sigma_{Ov}(Drain)$ as shown in fig. 4.

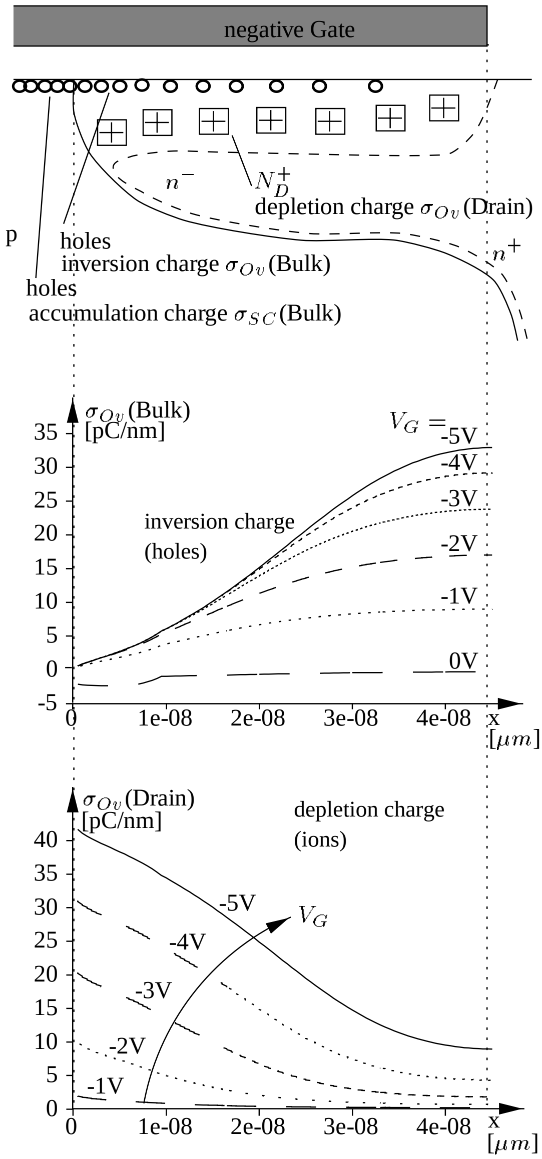

Figure 4. Charge distributions for negative gate voltages.

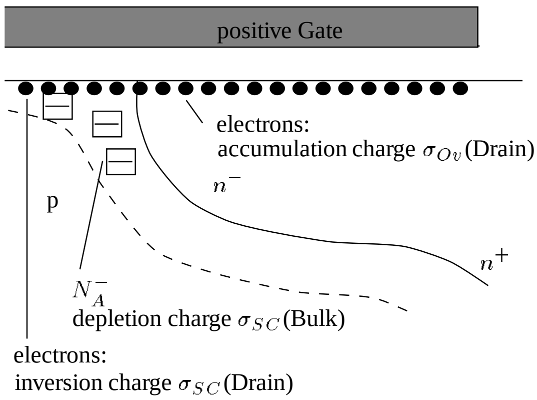

Figure 5. Charges for positive gate voltages.

However, in circuit simulators only the total charges are interesting. In fig. 6 the total charges are shown versus the gate voltage and compared with the one of the inner transistor $Q_{MOS}(Bulk)$ and $Q_{MOS}(Drain)$ respectively. This comparison was performed with the circuit simulator SABER on a device with a channel length of $0.25\mu m$. Fig. 6 demonstrates the importants of modelling the source and drain charges in comparison to the one of the inner transistor modelled by the existing BSIM3v3.1 C(V)-description.

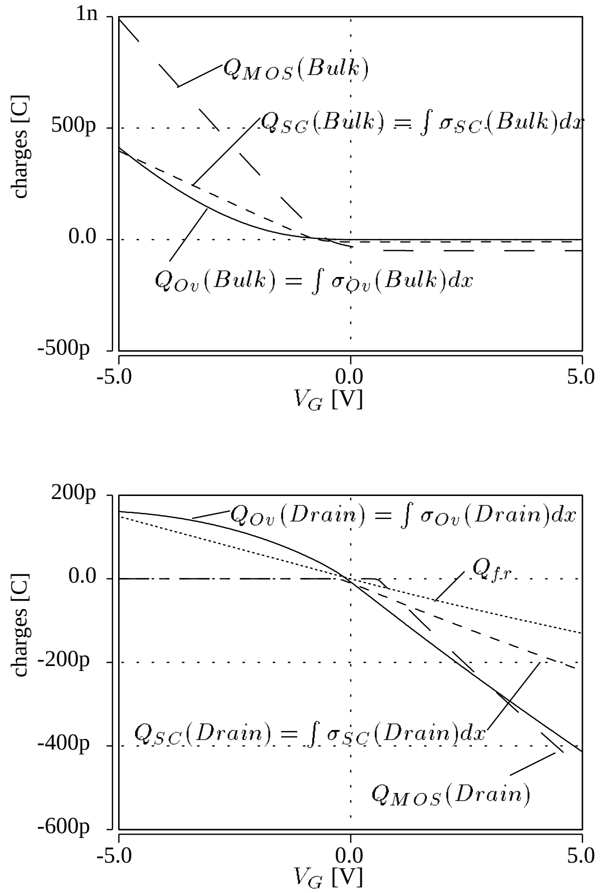

Figure 6. Voltage dependencies of the total charges.

The capacitances can calculated by

$$C_{SG} = \frac{\partial Q_S}{\partial V_G}, \quad C_{DG} = \frac{\partial Q_D}{\partial V_G}$$
$$C_{BG} = \frac{\partial Q_B}{\partial V_G}, \quad C_{GG} = \frac{\partial Q_G}{\partial V_G}$$

with

$$
\begin{aligned}
Q_S &= Q_{MOS}(Source) + Q_{SC}(Source) + \\
&\quad +Q_{Ov}(Source) + Q_{fr} \\
Q_D &= Q_{MOS}(Drain) + Q_{SC}(Drain) + \\
&\quad +Q_{Ov}(Drain) + Q_{fr} \\
Q_S &= Q_{MOS}(Bulk) + Q_{SC}(Bulk) + \\
&\quad +Q_{Ov}(Bulk) \\
Q_G &= -(Q_S + Q_D + Q_B)
\end{aligned}
$$

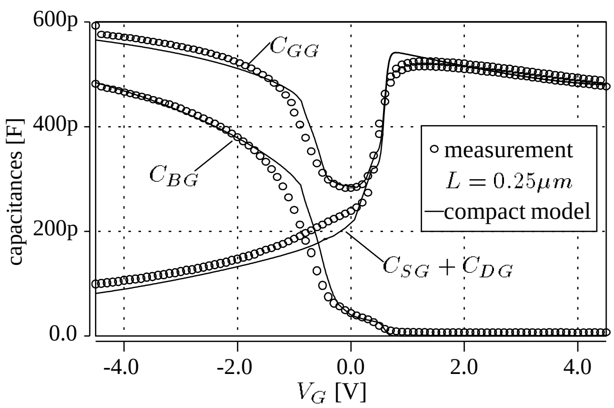

Figure 7. Comparision between measurements and the modified BSIM3v3.1 model.

4. Conclusion

Fig. 7 shows the SABER simulation with the modified BSIM3v3.1 model in comparision to measurements on a $0.25\mu m$ channel length device and proves an excellent agreement.

5. Appendix A

Using the depletion approximation the potential ψ over the non-gated diode can be determined. The charges in the overlap Q region can be calculated by [2]

$U_{GD} \leq U_{FB}$:

$$
\begin{aligned}
Q_{Ov}(Drain) &= \int C'_{ox}\left(\gamma\sqrt{-\psi_s} - V_1\right) dx \\
Q_{Ov}(Bulk) &= \int -C'_{ox}(U_{GD} - U_{FB} - \psi_S \\
&\quad +\gamma\sqrt{-\psi_S})dx
\end{aligned}
$$

$U_{GD} > U_{FB}$:

$$
\begin{aligned}
Q_{Ov}(Drain) &= -\int C'_{ox}U_{GD} - U_{FB} \\
&\quad -\psi - V_2)dx \\
Q_{Ov}(Bulk) &= 0
\end{aligned}
$$

$$
\psi_S = \frac{\psi_S^w}{1 + \frac{1}{f_3(-\psi_S^{st})}\ln\left[1 + \exp\left(f_3(\psi_S^{st} - \psi_S^w)\right)\right]}
$$

with

$$
\begin{aligned}
\psi_S^w &= -\frac{1}{4}\left(\frac{V}{\gamma}\right)^2 \\
\psi_s^{st} &= 2\phi_F + U_{BD} - \psi - m\phi_t \\
m &= f(U_G, U_D, U_B) \approx 6. \\
V &= -\gamma^2 + \gamma\sqrt{\gamma^2 - 4(U_{GD} - \psi - U_{FB})} \\
V_{1(2)} &= \frac{\sqrt{2\phi_t}}{\gamma + \sqrt{2\phi_t}} \frac{\ln(1 + f_{1(2)}(U_{GD} - \psi - U_{FB}))}{|f_{1(2)}|} \\
f_1 &= -2\frac{\gamma + \sqrt{2\phi_t}}{\gamma^2\sqrt{2\phi_t}} + f_2 \\
f_2 &= \frac{2}{3}\frac{\gamma}{\sqrt{2\phi_t}(\gamma + \sqrt{2\phi_t})^2}
\end{aligned}
$$

f_3 is a factor for a smooth transition of the surface potential ψ_S from depletion to inversion.

The charges of the space charge regions can be determined analogously.

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[1] BSIM3v3 manual, University of California, Berkeley, CA 94720, ftp site rely.eecs.berkeley.edu

[2] P. Klein, A compact-charge LDD-MOSFET model, ED-44, no. 9, Sep 97