Unified MOSFET model for all channel lengths down to quarter micron

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This work describes an analytical MOSFET model for analog circuit simulation. The new model, including the lateral electric field E_y contribution in a self-consistent way, describes the drain current of MOSFETs from long-channel to quarter-μ channel lengths with one model parameter set without discontinuities in derivatives of the drain current I_{ds}.

There have been several investigations to include short-channel effects in an analytical model[1], usually introducing additional model parameters. As a result many fitting parameters are required. Values of parameters fitted to measured I_{ds} are often not those predicted by technology. The most serious problem is that the derivatives of I_{ds} show kinks or even discontinuities at the transitions from the triode to saturation and subthreshold to linear regions. For analog circuit applications these must be avoided.

The new model is based on the charge-sheet model by Brews[2]. The current equation consists of diffusion and drift components, therefore I_{ds} is a smooth function of applied voltages. Since the original charge-sheet model is valid only for long-channel transistors, it has been further developed here to describe quarter-μ MOSFETs by introducing E_y into the theory. Inclusion of the E_y gradient in the Poisson equation causes a shift of the surface potential to higher values. This shift is that measured as the threshold voltage shift for reduced channel length. Thus the magnitude of the gradient can be extracted from measured subthreshold characteristics[3]. The result was used to calculate E_y. Since the model is described self-consistently on the basis of physical concepts, only one model parameter set is required for all channel lengths. The mobility reduction due to the E_y contribution is described by an empirical equation with physical parameter values taken from literature. Only two fitting parameters, the impurity scattering and the surface roughness scattering in the mobility equation, are added to process parameters (see Table 1). Though the new model reduces the number of fitting parameters drastically, it reproduces measured I_{ds} excellently for MOSFETs with all channel lengths (see Figs 1 and 2). The model shows that the main approximation of the charge-sheet model (zero thickness of the inversion layer) is still valid for deep submicron MOSFETs. The charge-sheet model needs several iteration procedures, which are not practical for circuit level simulation. Possibilities to eliminate the procedures are also shown. The model has been included in the parameter extraction program JANUS[4], which extracts model parameters automatically. Algorithms for parameter extraction are summarized.

[1] H. C. De Graaff and F. M. Klaassen, "Compact Transistor Modelling for Circuit Design," Springer-Verlag, Wien (1989).
[2] J. R. Brews, Solid-State Electron., 21, 345 (1978).
[3] M. Miura-Mattausch and H. Jacobs, SSDM Extended Abstract, 259 (1990).
[4] U. Weinert and A. Gilg, 6. Symposium in Wien, 561 (1990).

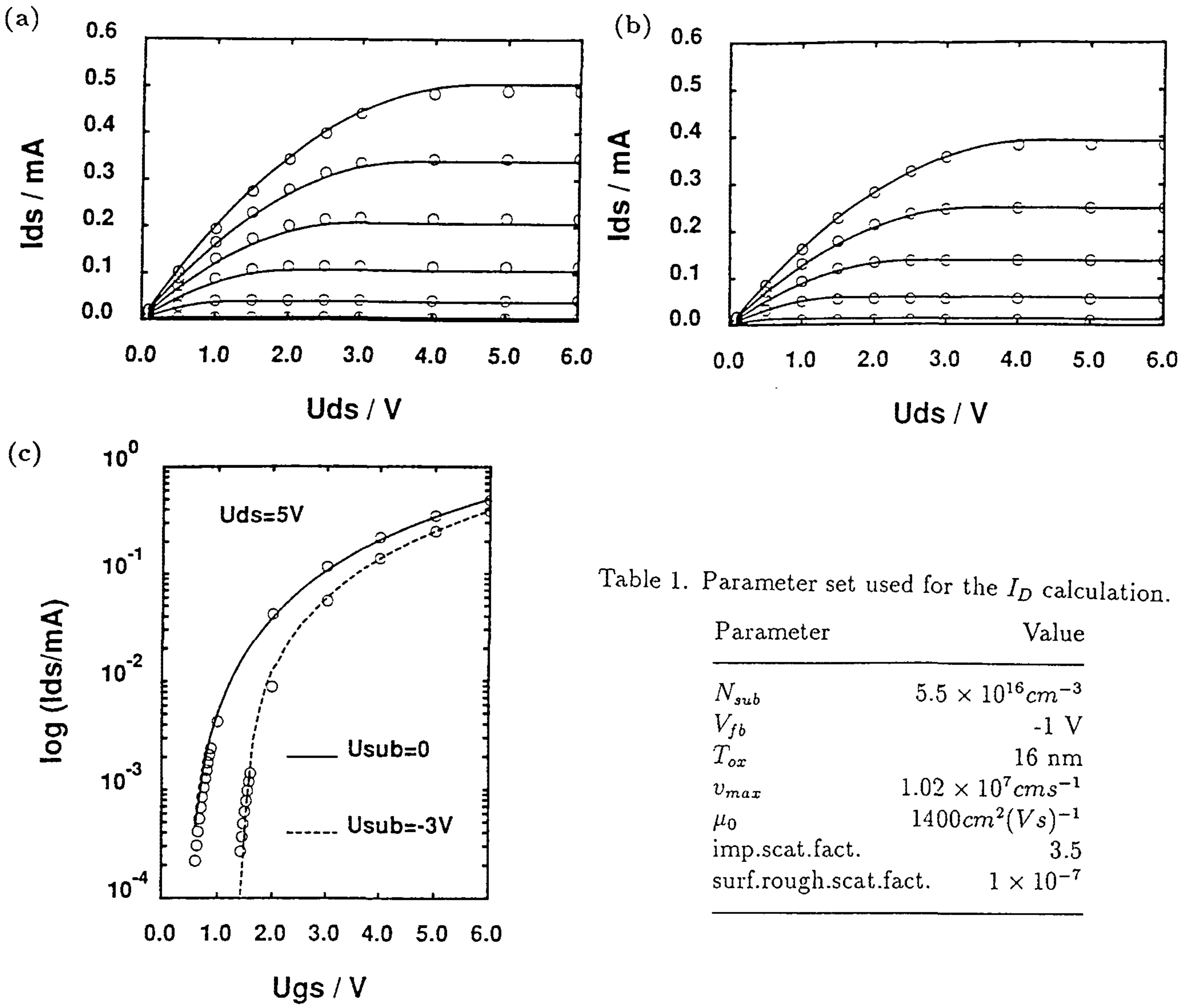

Fig. 1. Calculated I-V characteristics of $L_{eff} = 9.7\mu m$. (a) for $U_{sub} = 0$, (b) for $U_{sub} = -3V$, and (c) $U_{ds} = 5V$. Circles are measurments.

Table 1. Parameter set used for the I_D calculation.

Parameter	Value
N_{sub}	$5.5 \times 10^{16} cm^{-3}$
V_{fb}	-1 V
T_{ox}	16 nm
v_{max}	$1.02 \times 10^7 cms^{-1}$
μ_0	$1400 cm^2 (Vs)^{-1}$
imp.scat.fact.	3.5
surf.rough.scat.fact.	1×10^{-7}

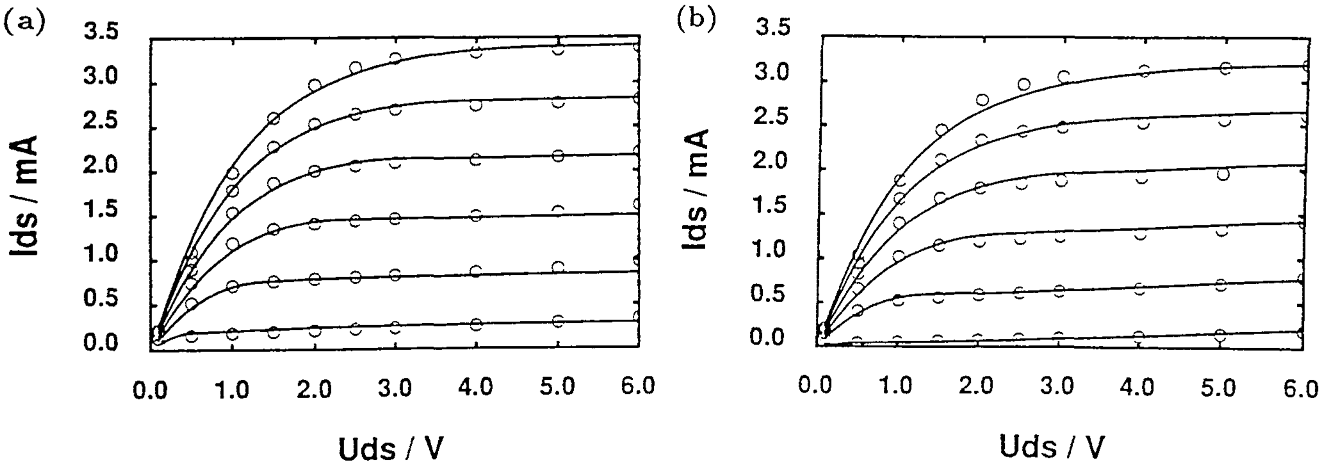

Fig. 2. Calculated I-V characteristics of $L_{eff} = 0.4\mu m$. (a) for $U_{sub} = 0$ and (b) for $U_{sub} = -3V$. The same parameter set as Fig. 1 is used.