MOSFET Model with a Small Set of Parameters for Electronic Engineering Education

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Abstract

Adequate and understandable MOSFET models are presently a must for the design of integrated circuits. Most of the existing MOSFET models, however, are too complex and/or do not comply with basic principles of physics. We propose here the use of ACM model, a very simple transistor model, together with a set of easily implemented experiments to determine the ACM parameters for the training of students for integrated circuit design. The use of the ACM model by our students has allowed them to easily correlate the model parameters and the electrical characteristics of MOSFET's.

1. Introduction

The explosive growth of applications of CMOS circuits has increased the number of integrated circuit (IC) designers who work physically separated from the foundry. In this context, MOSFET models are the key element linking design and fabrication. Most of the existing MOSFET models, however, are not adequate for design due to reasons such as violations of basic principles of physics, complex equations to describe the MOSFET behavior, excessive number of parameters, and lack of physical meaning of parameters. The inadequacy of these models is one of the main reasons behind the shortage of skilled IC designers, especially analog ones.

In order to provide electronic designers with a better understanding of the MOS transistor, we propose a set of laboratory and simulation experiments to determine the fundamental parameters of a transistor model, namely, the ACM (Advanced Compact MOSFET) model [1-3], developed at the Federal University of Santa Catarina.

This paper summarizes the characteristics of the ACM model and the strategy employed to extract the model parameters from a very simple set of experiments. This strategy has been employed to train students for IC design and has resulted in a much better understanding of the correlation between model parameters and the transistor properties.

2. Description of the ACM model

ACM is a physics-based MOSFET model described by a small set of parameters. The use of the substrate voltage as the reference voltage allows for a symmetric role of source and drain. The equations for the ACM model are presented in references [1-3]. The eleven parameters of the intrinsic MOS transistor described in Table I together with W (channel width) and L (channel length) allow us to simulate the transistor behavior for any set of applied voltages. All parameters but the last three in Table I are conventional parameters of MOS transistor models available in SPICE-like simulators.

Table I – Parameters of the ACM MOSFET model

Parameter	Description	Unit
VTO	Zero-bias threshold voltage	V
GAMMA	Body-effect parameter	$V^{1/2}$
PHI	Surface potential	V
TOX	Gate oxide thickness	m
LD	Lateral diffusion	m
XJ	Junction depth	m
UO	Low-field mobility	cm^2/Vs
VMAX	Saturation velocity	m/s
THETA	Mobility reduction parameter	V^{-1}
SIGMA	Drain induced barrier lowering parameter	m^2
PCLM*	Channel length modulation parameter	-

*LAMBDA in a previous version of the ACM model.

3. Extraction of the ACM parameters

The small number of physically based parameters in the ACM model not only simplifies the description of the device but also reduces the complexity of parameter extraction. We have employed three methods for the extraction of the ACM parameters:

1. The mapping of BSIM parameters to ACM parameters;

2. Experimental determination of the ACM parameters;

3. Determination of ACM parameters from simulation.

In the first method, we convert directly some BSIM parameters to ACM parameters, e. g., VTO and TOX, or use analytical expressions, two examples of which are here represented as GAMMA=f_γ(NSUB,TOX), THETA=f_θ(UA,UB,TOX), for the mapping of the parameters from BSIM or other MOSFET model to the parameters of the ACM model.

We have developed a set of very simple circuits, which require conventional laboratory equipment only, to determine the ACM parameters. The basic concept behind the strategy for experimental determination of the ACM parameters is that of biasing the transistor in a region where the parameter to be determined is the main reason for the observed measurement.

The conceptual circuit for the extraction of SIGMA is shown in Fig. 1. The bias current is such that the transistor operates in weak inversion, where drain-induced barrier lowering is dominant over channel-length modulation. To put it simply, SIGMA/L_{eff}^2=-1/A, where A=v_d/v_g is the transistor voltage gain. This circuit is useful not only for the purpose of extraction but also for linking a short-channel parameter, SIGMA, to the voltage gain of an amplifier.

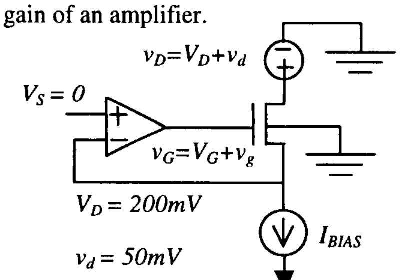

Fig. 1 – Circuit for the extraction of SIGMA

4. Results

The ACM parameters of an n-channel MOSFET from an off-the-shelf circuit, the C 4007, have been extracted by means of such simple circuits as the one shown in Fig. 1. Table II summarizes the results obtained. After the extraction has been completed, we generated some typical characteristics of the MOS transistor. One of the results of the simulation together with the experiment is shown in Fig. 2.

5. Conclusions

We propose a procedure to train electronic designers in transistor modeling and simulation. This procedure is based on the ACM model and the extraction of its parameters. Laboratory experiments or simulation can be used to determine the transistor parameters. The use of models based on physics such as ACM allows the students to easily correlate model parameters and the electrical properties of the transistor.

Table II – ACM parameters of the n-MOS transistor of the C4007 integrated circuit

Parameter	Value	Unit
VTO	1.40	V
GAMMA	2.3	$V^{1/2}$
PHI	0.64	V
TOX	10^{-7}	m
LD	10^{-6}	m
XJ	10^{-6}	m
U0	700	cm^2/Vs
VMAX*	10^5	m/s
THETA	0.123	V^{-1}
SIGMA	14.10^{-14}	m^2
PCLM	0.51	-
W#	8.10^{-4}	m
L	10.10^{-6}	m

* default value # fitting value L_{eff}=L-2LD

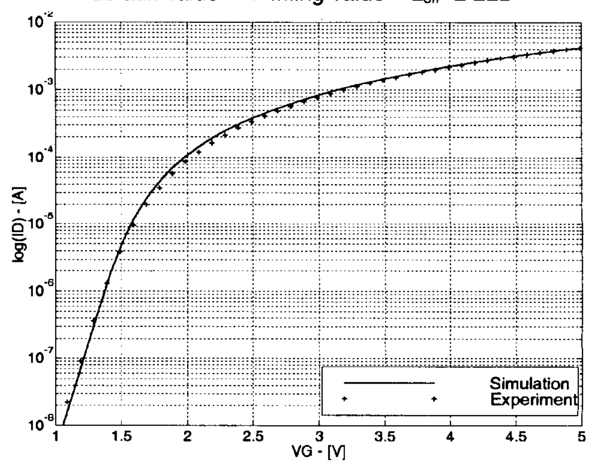

Fig. 2 – Simulation and experiment performed on the n-MOS transistor of the C4007

6. References

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