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Optimized parameter extraction using fuzzy logic

Rodrigo Picos [a,*], Oscar Calvo [a], Benjamín Iñiguez [b], Eugeni García-Moreno [a], Rodolfo García [b], Magali Estrada [c]

[a] *University of Balearic Islands, 07122 Palma, Balears, Spain*
[b] *Universitat Rovira i Virgili, Tarragona, Spain*
[c] *CINVESTAV, Mexico DF, Mexico*

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Abstract

Precise extraction of transistor model parameters is of much importance for modeling and at the same time a difficult and time consuming task. Methods for parameter extraction can rely on purely mathematical basis, calling for intensive use of computational resources, or in human expertise to interpret results. In this work, we propose a method for parameter extraction based on fuzzy logic that includes a precise knowledge about the function of each parameter in the model to create a set of simple fitting rules that are easy to describe in human language.

To simplify the computational effort, the parameter fitting rules work using only data at specific points (e.g. the distance between the calculated curve and the measured one at VDS corresponding to 50% of the maximum current). If necessary, a more accurate implementation can be used without altering the basic underlying philosophy of the method.

In this work, the method is applied to extract model parameters required by Level 3 bulk MOS model and by a compact model for TFTs used in the Unified Model and Extraction Method (UMEM), which is based on an integral function. Results obtained show that the method is quite insensitive to the initial conditions and that it is also quite fast. Extension of this method for more complex models requires only the creation of the corresponding rule base, using the appropriate measurements. The method is especially useful for production testing or design.

Keywords: Thin film transistors; Fuzzy control; Parameter extraction; Compact modeling

1. Introduction

Extraction of device model parameters from measured I–V characteristics is a complex task in modern models. It may involve the determination of hundreds of parameters, some of them correlated, requiring global optimization methods and human expertise.

One way to simplify this task is to use direct extraction methods for these parameters, or at least for some of them. This last approach eases the entire extraction procedure in the case of models with large number of parameters, reducing the iteration time in case of optimization when these values are to be used as starting data. As an example, we can mention the extraction of the threshold voltage [1–5] or the saturation voltage [6–8], that can be considered fundamental.

Once the parameters have been extracted, most of the direct extraction methods need a second step to take into account the interactions among the different parameters. This leads to the use of global methods (SaPOSM [9], Fast Diffusion [10], Genetic algorithms [11], etc) to find the set of values that can best fit the experimental data. SaPOSM and Fast Diffusion are based on calculating derivatives and

* Corresponding author. Tel.: +34 971173227; fax: +34 971172486.
E-mail address: rodrigo.picos@uib.es (R. Picos).

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are thus computationally expensive and difficult to code. Genetic algorithms, on the other hand are easy to code, but they can present lack of precision. Moreover, all these methods are based only on mathematics and, thus, they do not use of the knowledge a human expert would deploy to do this task.

Fuzzy logic is a widely used technique in control and identification applications. Its main advantages over other techniques can be synthesized as follows: it does not require a precise description of the behavior of the system. For example, it only needs to know that increasing the value of the threshold voltage implies that the ids–vgs curve shifts to the right and vice versa. On the contrary, in other methods such as SaPOSM, it is necessary to know the precise behavior of I_{DS} and V_{TH} in order to be able to calculate the derivatives that are the core of the process.

In this paper, we present a method to extract the different parameters of transistor models based on fuzzy logic. To show its versatility, the method is demonstrated for determining parameters required by simplified Level 3 MOSFET model and also for the first TFT compact model and extraction procedure called the Unified Modeling and Extraction Method (UMEM), applied to organic TFTs in [12].

UMEM, as any direct extraction method needs some human know-how to be performed successfully. In this paper, we apply fuzzy logic techniques to include expert's knowledge in a systematic way in the process. The procedure is extremely rapid without loosing precision and repeatability, paving the road to industrial use of these devices.

The paper is organized in four sections. Section 2 reviews the basics of fuzzy control and fuzzy logic. Section 3 applies the method to extract Level 3 parameters for a bulk MOSFET. In Section 4, the method is used with the UMEM TFT model and, finally, Section 5 details the main conclusions of the paper.

2. Fundamentals of fuzzy logic

Parameter extraction procedures can be considered a control problem where an optimum operation point has to be determined to achieve a minimum error between model and measured data. For this reason, we can use control procedures to perform parameter extraction.

Among control techniques, one that is especially easy to use is the one based on verbal rules that control the behavior of the system, which is called fuzzy control [13–15]. It is based on the theory of fuzzy sets and fuzzy logic [13]. This technique is based on the principle that imprecise data can be classified into sets having fuzzy rather than sharp boundaries, which can be manipulated to provide a framework for approximate reasoning in the presence of imprecise and uncertain information. For instance, given a datum, x, a fuzzy set A is said to contain x with a degree of membership $\mu_A(x)$, where $\mu_A(x)$ can take any real value in the domain [0,1].

Fuzzy sets are often given descriptive names (called linguistic variables) such as POSITIVE; the membership function $\mu_{\mathrm{POSITIVE}}(x)$ is then used to reflect the similarity between values of x and the contextual meaning of POSITIVE. For example, if x represents the difference between the experimental and calculated currents in the $I_{DS} - V_{GS}$ curves at a given value of V_{DS}, and POSITIVE is to be used to determine the fitting, then POSITIVE might have a membership function equal to zero for values below 0 and equal to one for values above 10%, with a curve joining these two extremes for intermediate values. The truth degree of the statement "*the two curves are separated by a positive distance*" is then evaluated by reading off the value of the membership function corresponding to the distance.

Logical operations on fuzzy sets require an extension of the rules of classical logic. The three fundamental Boolean logic operations (intersection, union, and complement) have fuzzy counterparts defined by extension of the Boolean logic rules. A fuzzy expert system uses a set of membership functions and fuzzy logic rules to reason about data. The rules are of the form "if x is POSITIVE and y is NEGATIVE then z is MEDIUM," where x and y are input variables, z is an output variable, and POSITIVE, MEDIUM, and NEGATIVE are linguistic variables. The set of rules in a fuzzy expert system is known as the rule base, and together with the database of input and output membership functions it comprises the knowledge base of the system.

A fuzzy expert system works in four steps. The first step is *fuzzification*, during which the membership functions defined over the so called universe of discourse (the expected range of variation) of the input variables are applied to their actual values, to determine the degree of truth for each rule. Next is *inference*, during which the truth-value for the premise of each rule is computed and applied to the conclusion part of each rule. This results in one fuzzy set to be assigned to each output variable for each rule. The third step is *composition* in which all of the fuzzy sets assigned to each output variable are combined together to form a single fuzzy set for each output variable. Finally comes *defuzzification*, which converts the fuzzy output set to a crisp (non-fuzzy) number. A fuzzy logic controller may then be implemented as a system performing fuzzy operations on fuzzy sets represented by linguistic variables in a qualitative set of control rules (see Fig. 1).

A fuzzy logic controller (FLC) is just a special controller that is used to modify the dynamics of a closed-loop system based on heuristic rules. It elaborates a control law from a set of rules that mimic the reactions of a human expert to various situations, mainly, when the system to be controlled is vaguely defined, is very complex and nonlinear, or when its dynamics is unknown and the sensors provide noisy and incomplete data. In our case, these rules will be provided by the knowledge about the transistor model, which is, obviously, a complex and nonlinear system.