Development of SiC MOSFET electrical model and experimental validation: improvement and reduction of parameter number

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***Abstract*—In this work, a new approach for electrical modeling of Silicon Carbide (SiC) MOSFET is presented. The developed model is inspired from the Curtice model which is using a mathematic function reflecting MOSFET output characteristics. The first simulation results showed good agreement with measurements. Improvement is needed in order to increase model accuracy and to take into account the influence of the junction temperature on device characteristics.**

***Keywords*—SPICE model; Silicon Carbide (SiC); MOSFET**

I. INTRODUCTION

In power electronics field, engineers must simulate electrical circuit before building an electrical system. During this phase, a good electrical model of transistors is mandatory because it gives the necessary indications on the behaviors of the systems under different conditions. That is why having a good transistor model is critical. Often, a complex model provides a better accuracy, but it has a longer simulation time. Conversely, a simple model has much shorter simulation time, but often with a mediocre accuracy. Electrical engineers always have to compromise these two aspects.

In most applications, Silicon (Si) power devices play a dominant role because technologies are mature. However, foreseeing their limits [1], a lot of efforts were put in order to find alternative devices. Wide band gap materials such as Silicon Carbide (SiC) and Gallium Nitride (GaN) are two most promising materials to replace Silicon in power devices. Presently, SiC power devices are targeted for replacing Si power devices in high voltage applications. SiC MOSFETs and SiC Schottky diodes are already successfully commercialized and replaced their Si counterparts in some applications with higher overall performances [2], [3]. Electrical models of these devices are necessary for engineers to contemplate which solutions to choose while considering all aspects: performance, price, harsh conditions … A great amount of works are put into accurately modeling these devices, particularly SiC MOSFET.

In the literature, many models of SiC MOSFET have been proposed [4]. McNutt *et al.* [5] have efficiently adapted a physical model of Si IGBTs for SiC MOSFETs. While the advantage of this model is presenting the MOSFET with physical meaning, it is still limited because of its complexity and its accuracy.

On the industrial side, SiC MOSFET manufacturers also provide electrical models for their own power devices. Some of them (STM, ROHM and CREE Wolfspeed devices) are analyzed and validated by measurements [6]. These die manufacturers have used the level 1 Si Model (STM), the EKV model (ROHM and CREE Wolfspeed) and the Curtice model (CREE Wolfspeed) for their devices, even though the level 1 Si model and EKV model do not properly adapt to SiC devices, The Curtice model gives a better accuracy and adaptation for these devices. Since its creation which was initially used for GaAs FET [8], consequential works have been completed to adapt this model to MOSFETs. An improved modeling based on Curtice model for SiC MOSFET is proposed [7].

Taking a step back, the idea behind Curtice model is that the hyperbolic tangent function has the same form as the output characteristics of MOSFET. Using this function, we can easily represent output characteristics of SiC MOSFET with a good accuracy by adjusting fewer parameters in the MOSFET equations.

It is natural to think about other functions having the same form and to extend the model by using these functions. The idea here is to see if we can minimize the number of parameters and so decrease the complexity of the model while maintaining the same level of accuracy.

In this particular work, we build our model using the following function instead of the hyperbolic tangent function:

$$f_d(x) = \frac{x}{|x| + b} \qquad (1)$$

This function is relatively simple comparing to the hyperbolic tangent function.

II. SIC MOSFET MODELING

A. State of the art of Curtice model for SiC MOSFET

In this section, we will present our model of SiC MOSFET. The original Curtice model of MOSFET channel is the following [9]:

$$I_{DS} = f_g(V_{GS}) \times f_d(V_{DS}) \qquad (2)$$

Where:

$$f_g(V_{GS}) = A_0 + A_1 V_{GS} + A_2 V_{GS}^2 + A_3 V_{GS}^3 \qquad (3)$$

$$f_d(V_{DS}) = \tanh(\gamma V_{DS})\,(1 + \lambda V_{DS}) \qquad (4)$$

The function $f_g(V_{GS})$ represents transfer characteristics while the function $f_d(V_{DS})$ represents output characteristics of MOSFET. Some modifications have been realized in order to adapt the model to SiC MOSFET [6].

The function of f_g has been changed from a cubic polynomial to an algebraic fraction function [6]. The idea behind this change is that the new function f_g suits better the transfer characteristics of SiC MOSFET.

The function f_d, on the other hand, has been the same hyperbolic tangent function as the Curtice model's one.

B. New model for SiC MOSFET

Firstly, we separate the MOSFET equation by blocks and normalize the two functions that represent transfer characteristics and output characteristics. The MOSFET equation will have the following formula:

$$I_{DS} = C \times f_g(V_{GS}) \times f_d(V_{DS}) \times (1 + \lambda V_{DS}) \qquad (5)$$

Where:

C is a constant which relates to the saturation current of SiC MOSFET.

$f_g(V_{GS}) = \left(\frac{V_{GS}^n}{V_{GS}^n + a^n}\right)^m$ (6), is a function V_{GS}, with coefficients a, n, m.

$f_d(V_{DS}) = \frac{V_{DS}}{|V_{DS}| + b}$ (7), is a function of V_{DS}, with coefficient b.

$1 + \lambda V_{DS}$ is the modulation factor with λ is channel-length modulation parameter. This factor allows the I_{DS} compensate the small augmentation of drain current when V_{DS} becomes very large (in saturation mode).

Analysis of the model:

In the function $f_g(V_{GS})$, the added coefficient a allows having a better dynamic while fitting the model with measurement. By adjusting the values of a, n and m, we can have a different threshold voltage and different curves of the function f_g. The curve of $f_g(V_{GS})$ with different sets of parameters (a, n, m) is illustrated in figure 1.

The function $f_d(V_{DS})$ has the same curve as the hyperbolic tangent function in the Curtice model. The figure 2 shows several forms of the function $f_d(V_{DS})$ with different values of b.

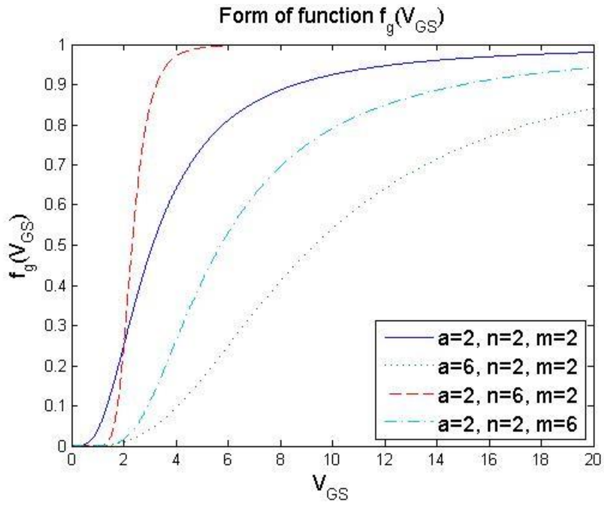


Fig. 1. Curves of the function $f_g(V_{GS})$, with different set values of coefficients (a, n, m).

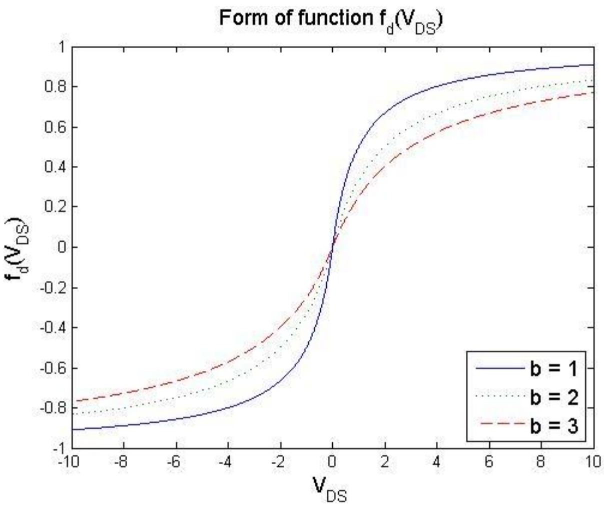


Fig. 2. Curves of the function $f_d(V_{DS})$ with different values of b.

The value of $f_d(V_{DS})$ tends to 1 when V_{DS} becomes very large. The smaller b is, the faster $f_d(V_{DS})$ approaches its asymptote.

In order to have a complete MOSFET equation, we need to find totally 6 mentioned coefficients: C, a, n, m, b, λ.

The conventional procedure is to acquire the output characteristics of devices by experimental measurement. Afterwards, using curve fitting techniques, we will be able to find a set of coefficients that minimize the difference between the simulation curve and the measurement one (method of Least-Squares). The found coefficients will be then employed in the model to plot the simulation curve. A comparison between the simulation curve and measurement will be made in order evaluate the accuracy of the model.

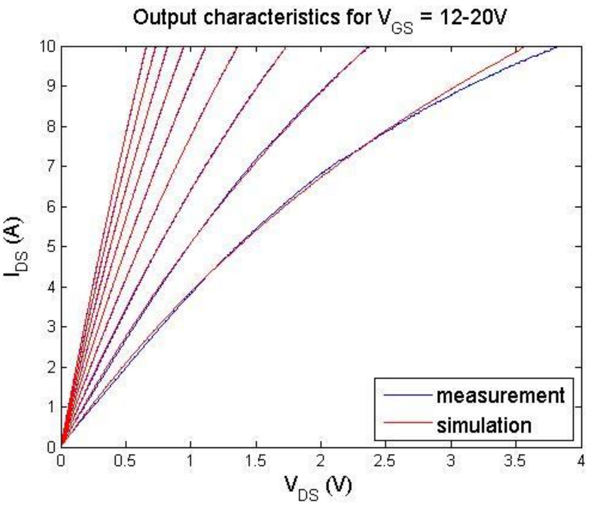
III. SIMULATION AND MEASUREMENT

In this third section, in order to validate the accuracy of the built model, we will make use of this model on different SiC MOSFETs from different manufacturers. Two selected SiC MOSFETs are: SCT50N120 (from STM) and SCT2280KE (from ROHM).

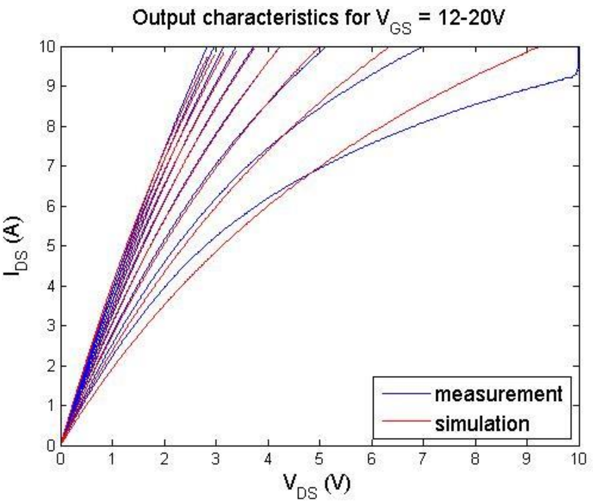
Forward output characteristics of these devices are measured by using the curve tracer HP4142b. Here, the drain-source voltage V_{DS} was measured under different values of the gate-source voltage V_{GS} (from 12V to 20V) when the drain current I_{DS} varies from:

- 0 to 10A for forward conduction.
- 0 to -10A for reverse conduction.

In figure 3, simulation and measurement comparison of forward output characteristics of these SiC MOSFETs are illustrated.

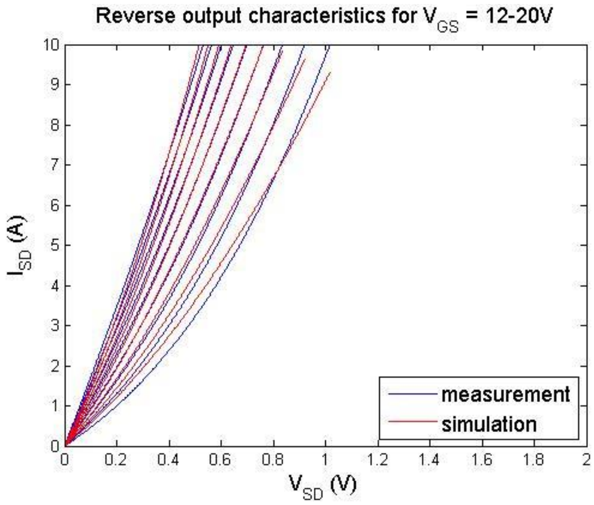


(a)

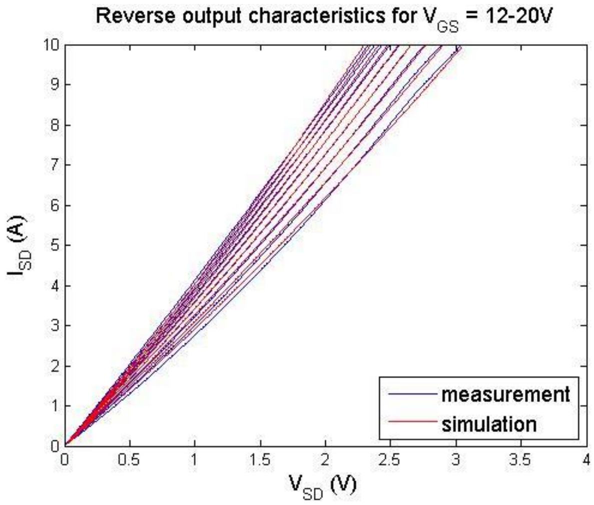


(b)

Fig. 3. SiC MOSFET forward output characteristics: simulation vs measurement (a) SCT50N120, (b) SCT2280KE.



(a)



(b)

Fig. 4. SiC MOSFET reverse output characteristics: simulation vs measurement (a) SCT50N120, (b) SCT2280KE.

As we can see in figure 3, the model gives a pretty good accuracy of forward characteristics at high gate-source voltage V_{GS} for both devices. While it still maintains a good precision at low gate source voltage V_{GS} for STM device, its precision decreased for ROHM device under these conditions (V_{GS} = 12-13V).

Figure 4 shows the simulation and measurement comparison for reverse output characteristics (I_{SD} as function of V_{SD}). The model shows a promising accuracy for ROHM device. However, it only give a good precision for STM device under high gate-source voltage V_{GS}. In the case of low gate-source voltage (V_{GS} = 12V), the model still needs to be improved.

IV. CONCLUSION

This paper presents a behavioral electrical model of SiC MOSFETs. Following the funding idea of Curtice model, a different function is used instead of the hyperbolic tangent function in order to represent the output characteristics of MOSFETs. As illustrated in figure 2, the model showed a promising modeling accuracy vs. measurement. However, the model still needs to be improved to better address static output characteristics at medium gate-source voltage.

The model only uses 6 parameters for the functionality of MOSFET channels. For comparison, another model [7], which was also built on the Curtice model, has 12 parameters. However, this model already takes into consideration the variations of characteristics with the junction temperature.

Taking into account the influence of the junction temperature in our model is a first development to follow.

Secondly, this work should be extended to a fully completed model of SiC MOSFET with dynamic characteristics, body diode characteristics and other aspects.

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