Analysis of SPICE Models for SiC MOSFET Power Devices

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Abstract: **This work compares four SiC power MOSFET models for SPICE provided by main device manufacturers: STMicroelectronics, CREE and ROHM. Model complexity and structures are analysed. Model accuracy is assessed by comparing simulation results to static output characteristics given in the respective device datasheets.**

Keywords: **modeling, MOSFET, SiC, SPICE.**

I. Introduction

In recent years, power MOSFETs manufactured from silicon carbide were introduced to the market. They offer greater voltage capabilities and lower static and dynamic power loss than silicon MOSFETs [1] as well as lower power loss as compared to similarly rated IGBTs [2]. However, in order to take these advantages into account in circuit design, appropriate simulation models are necessary.

Models of for four SiC MOSFET devices rated for 1200 V and approximately 20 A were analysed and revised: SCT20N120 from STMicroelectronics (further referred to as ST model), C2M0160120D and C3M0065090D from Cree (C2M and C3M model, respectively) and SCT2160KE by ROHM (ROHM model). In Sections II and III, model code structures and subcircuit equivalent schematics will be analysed. These are important from the point of view of customisability. Next, simulations results will be presented and compared to datasheet characteristics. In this first study, they will be limited to forward bias and to the low drain-source voltage region as it is crucial for power electronic applications, influencing the power loss.

II. Model Code Structure

All the analysed models are designed for application in SPICE-based environments, specifically PSpice or LTSpice.

The code of the ST model [3] is organized linearly in one single block. The behaviour of the MOS structure is described in this model by an ABM (analog behavioural model) current source. This source realises quite a complicated conditional structure, which contains the LEVEL1 MOS model equation. Other model relationships are defined using functions. Equation parameters for all model relationships are given separately by standard parameter definitions. These statements are placed within the code prior to each related equation. Parameter names are related to their designation in model equations or to their physical role in corresponding model parts. It's worth noting that seven parameters and one relationship appearing in the code are in fact unused.

The code of the C2M model [4] is divided into parts that correspond to the MOS structure, the body diode and the gate capacitances. In a way similar to the ST model, the MOS component of C2M is implemented using two ABM current sources. They correspond to the forward and reverse parts of the Enz-Krummenacher-Vittoz (EKV) MOSFET model.

In contrast to the ST model, all the parameters defined in the C2M model code are named using numbering in the order of their appearance. Thus, these names don't provide any information about the meaning of the respective parameters. Another difference between the ST and the C2M model lies in the description form of model relationships: in the C2M model, all of them are expressed explicitly in the corresponding ABM current or voltage sources.

The C3M model has a code structure more complicated than any other analysed model. It has a hierarchic structure. The file includes models fort the bare die as well as for the packaged component. Both are built around the same subcomponent which describes the behaviour of the die itself. The latter model also includes separate subcomponents to describe gate-to-drain and drain-to-source capacitances.

Die behaviour model is based on the equations of the modified Curtice-Ettenberg FET model. All equations and relations are implemented in the C3M model in the form of functions with pre-defined parameters. Those parameters are named according to the order of their appearance in the functions. Just as in C2M model, parameter names in C3M do not provide adequate information on their assignment and physical meaning. The C3M model code is also complicated by fitting functions used and the high number of their parameters.

The organisation of the ROHM model is similar to the ST one, with one single block. Model parameters are not clearly defined as they are given as numerical values in function definitions. However, the physical meaning of each function can be supposed from the respective function name.

III. Model Subcircuit Topology

The topologies of the analysed models was visualised by building electrical schematics corresponding to the respective SPICE codes. As already mentioned, a feature common to all the analysed models is the use of ABM components: controlled current and voltage sources described with arbitrary equations.

The highest topology complexity can be seen for the ST model (Fig. 1 a). Despite its code having a linear structure, in its topology fragments can be distinguished corresponding to specific device structure components (body diode,

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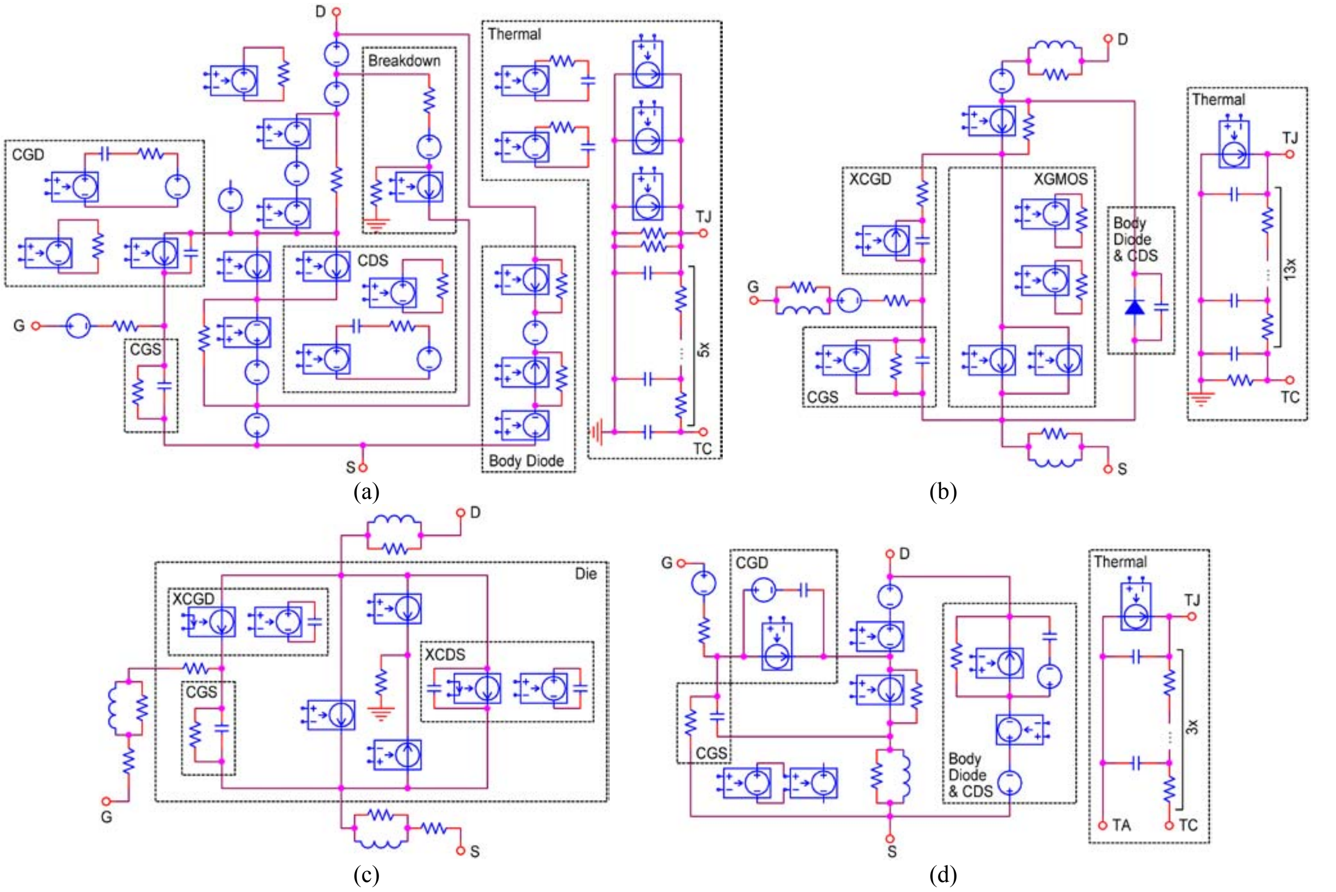

Fig. 1. Simplified electrical schematics (dependent source inputs and some ground connections omitted) for (a) ST, (b) C2M, (c) C3M and (d) ROHM models

capacitances, MOS structure). While the ROHM model has a similar code form, it contains less components (Fig. 1 d).

To the contrary, models proposed by Cree (Figs. 1 b and c) have hierarchic code structures, as it was previously described. Their schematic topologies are relatively simple. However, the mathematic formulae which these schematics implement through ABM source equations is very complex. It should also be noted that the C3M model lacks a thermal part and, consequently, electro-thermal coupling which are present in all the other models. These thermal parts are composed of several RC couples in each case. However, their number varies considerably between models, from 3 in ROHM to 14 in C2M.

IV. Static Behaviour Modelling

Simulations for all the models have been performed using PSpice in order to avoid any effect of different computational kernels on results obtained. Static forward characteristics obtained this way were compared with those given by device manufacturers in the respective device datasheets. This analysis has been carried out for the junction temperature of 25 ºC. This was achieved by applying this value directly to the junction thermal terminal of each model (except C3M which misses a thermal part) while floating the case thermal terminal.

The Cree (C2M and C3M) were designed for the LTSpice simulator. In order to use them in PSpice, they had to be modified by adding a voltage source reproducing the junction temperature connected to an *RC* branch. This broke a direct connection between the thermal and the electrical parts of the model by introducing a small time delay to the coupling loop, which ensured simulation convergence. This solution was adopted from the ST model.

In the case of the C3M model, further modifications were needed for components corresponding to power MOSFET capacitances. They were originally represented using arbitrary behavioural current sources in order to implement variable capacitance relationships. However, in PSpice, this kind of current source does not support arbitrary relationships. For this reason, they had to be replaced with ABM voltage-dependent current sources.

It can be seen from Fig. 2 a that the ST model is unable to properly reproduce shapes and numerical values for the SCT20N120 transistor characteristics in between weak and strong inversion region.

It is also clearly seen (Fig. 2 b) that the C2M model cannot cope with the task of accurate simulation of the C2M0160120D device characteristics. Simulation shows lower voltage drop for a given drain current in comparison to datasheet characteristics. This is highly undesirable for circuit designers, as it results in power loss underestimation that leads to selecting an unsuitable device that is likely to fail. Moreover, using this model both simulators (PSpice and LTSpice) were unable to calculate the operating point for a zero value of drain-source voltage due to convergence issues.

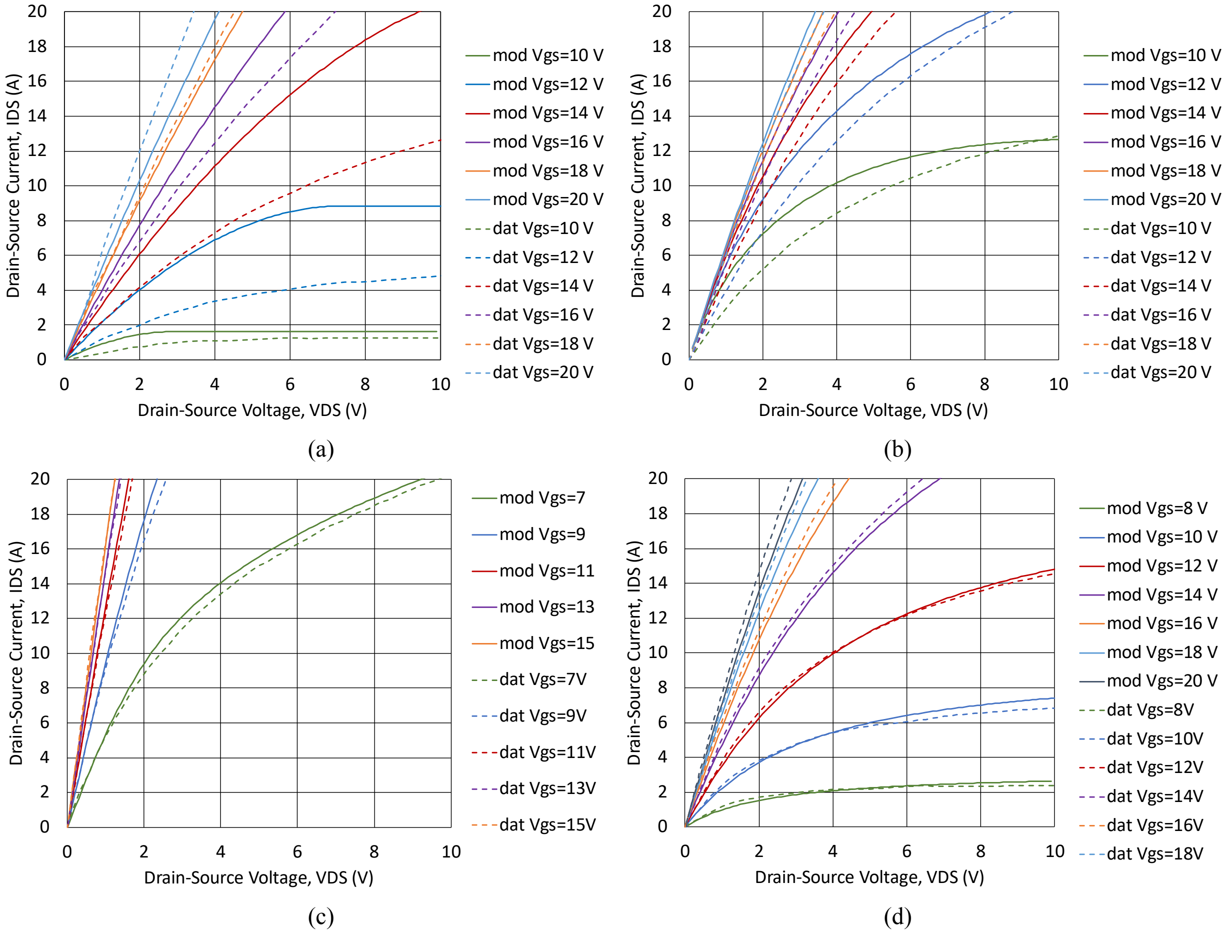

Fig. 2. Simulated (mod) and datasheet (dat) output characteristics at T_J = 25 °C for (a) ST, (b) C2M, (c) C3M and (d) ROHM

In comparison to the above two models, the C3M model has been found to be more accurate as tested for the C3M0065090D transistor (Fig. 2 c). Model authors remark in model code it is intended for use in strong inversion only and its accuracy is limited in weak and moderate inversion at this point. It can be observed in Fig. 3 c that its accuracy is indeed limited in weak and moderate inversion, but it is still higher than that of the ST and the C2M models.

The highest conformity for static output characteristics has been observed for the ROHM model. It can be seen (Fig. 2 d) that this model is accurate in both linear and saturation regions.

V. Conclusions

From the presented analysis it is clear that the general approach taken by each manufacturer is similar in that all models have the form of sub-circuits containing ABM components. However, specific topologies are different not only for different manufacturers but also for different technologies (2nd and 3rd generation Cree devices).

None of the models is easy to customise. However, this is due to different reasons. In the case of the ST model, it is its complex subcircuit topology and high number of components. Topologies are simpler for Cree models and their codes are hierarchically organised, but function and parameter names are not explanatory and mathematical formulae are complex. In the ROHM model, parameter values are hard coded as numbers, which makes it hard to differentiate between model parameters and relationship coefficients. Comparison of simulation results with datasheet characteristics led to the conclusion that it is the ROHM model that provides the highest result accuracy for forward bias. The worst accuracy is offered by the ST and the Cree C2M models.

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