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Modeling and analysis of the characteristics of SiC MOSFET

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Abstract. Although the superior performance of SiC MOSFET devices has been validated by many studies, it is necessary to overcome many technical bottlenecks to make SiC MOSFET gradually replace Si-based power devices into the mainstream. In view of the current situation where the performance of SiC MOSFETs in power conversion devices cannot be evaluated well at this stage, it is necessary to carry out fine modeling of SiC MOSFETs and establish accurate simulation models. In this paper, the powerful mathematical processing capability and rich modules of Matlab/Simulink are used to build a SiC MOSFET model, and then the product data sheet is compared with the fitted data. The results show that the switching simulation waveforms are in general agreement with the data sheet waveforms, and the error is less than 7%. Verifying the accuracy of the model and reducing the difficulty of modeling, it provides a new idea for establishing the circuit simulation model of SiC MOSFET in Matlab/Simulink.

1. Introduction

In modern times, going with the rapid development of power electronic technology, the performance of silicon-based power devices cannot meet the increasing requirements of modern technology any more. In the past few years, silicon carbide as the representative of the third generation of wide band gap semiconductor materials appeared. Silicon carbide has many advantages, such as low switching loss, low conduction resistance and stable operating characteristics at high temperature, which makes it become a new research focus in the field of power electronics.^[1-3] From the current research status of SiC MOSFET, most manufacturers do not provide the corresponding simulation model. However, the study of SiC MOSFET characteristics and the establishment of accurate circuit simulation model can make it better plays its performance advantages. Therefore, it is very important to build SiC MOSFET model and build accurate simulation model.

In the past, most of the MOSFET modeling and simulation models is built in Pspice software; it is very difficult to build an accurate MOSFET model because Pspice software is deficient in mathematical equation processing. However, MATLAB/SIMULINK is very good at this. It has the power electronic circuit simulation and power system rich module resources. It uses S function module to expand the module library and customize its own Simulink module. It is coupled with the computing power of MATLAB, which can consider more complex formulas and features, and establish more accurate simulation models.^[7-10]

In view of the existing problems of SiC MOSFET modeling, the C2M0080120D SiC MOSFET power device has been commercialized by CREE company as a reference, and the mature modeling and analysis methods of SiC MOSFET in Pspice are used in MATLAB/SIMULINK. We make use of the properties of programmable function and the convenience of constructing the circuit model to



establish the exact equivalent model of SiC MOSFET. Finally, it compares the data sheet receipts with simulation results to verify the accuracy of the model. All modeling parameters are extracted from the data sheet. In the application of different manufacturers of SiC MOSFET power devices, it changes its internal functions and parameters according to the different parameters, in order to achieve the unique simulation of different manufacturers of power devices.

2. MOS tube property analysis

The static characteristic modeling of general MOSFET is standard long channel device model. The model is simple in structure, the process of solving equations is very convenient, and it can improve the accuracy and meet the requirements of simulation time.

The model uses the following expression to describe the device behavior of MOSFET under different voltages:

$$I_{DS} = 0 \quad V_{GS} \leq V_{TH} \quad (1)$$

$$I_{DS} = \mu C_{ox} \frac{W}{L} \left[(V_{GS} - V_{TH}) V_{DS} - \frac{1}{2} V_{DS}^2 \right] \cdot (1 + \lambda V_{DS})$$

$$V_{GS} > V_{TH} \ \& \ V_{DS} < V_{GS} - V_{TH} \quad (2)$$

$$I_{DS} = \mu \frac{C_{ox}}{2} \frac{W}{L} (V_{GS} - V_{TH})^2 \cdot (1 + \lambda V_{DS}) \quad (3)$$

$$V_{GS} > V_{TH} \ \& \ V_{DS} \geq V_{GS} - V_{TH}$$

$$K_p = \mu C_{ox} \quad (4)$$

As shown above, the expression describes the cut-off region, linear region, and the saturation region of MOSFET in turn. μ is carrier mobility, W is channel width, L is channel length, V_{TH} is threshold voltage, λ is channel length modulation parameter.

The threshold voltage V_{TH} decreases with increasing temperature. In traditional modeling, threshold voltage is usually modeled by linear fitting. This approach does not properly fit the temperature characteristics of the threshold voltage. Therefore, in order to improve the accuracy of the model, we need to accurately model the threshold voltage. We need to extract data on its transfer characteristic curve in C2M0080120D device manual. In addition, we have to draw, using HaoCurve software fitting, to get the formula (5)

$$V_{TH} = 5.048 - 0.015 \times T \quad (5)$$

The most important dynamic characteristic of SiC MOSFET is its switching characteristic, but the nonlinear capacitance in SiC MOSFET will affect its switching characteristic. The nonlinear characteristics of SiC MOSFET are mainly determined by the gate leakage capacity C_{gd} and drain source capacitance C_{ds} . Their existence affects the dynamic characteristics of MOS tube devices. Between the two parasitic capacitors, the gate leakage capacity C_{gd} has stronger nonlinearity, which is the key to build the dynamic model of MOSFET. Therefore, we need to study the nonlinear element C_{gd} in SiC MOSFET model, and propose a prototype of voltage control current, namely, Simulink Receiver receiver circuit simulation model.

3. Model establishment

The above modeling and the simulation model are implemented in Matlab/Simulink, and the subsystem external structure of the SiC MOSFET model is created as shown in Figure 1.

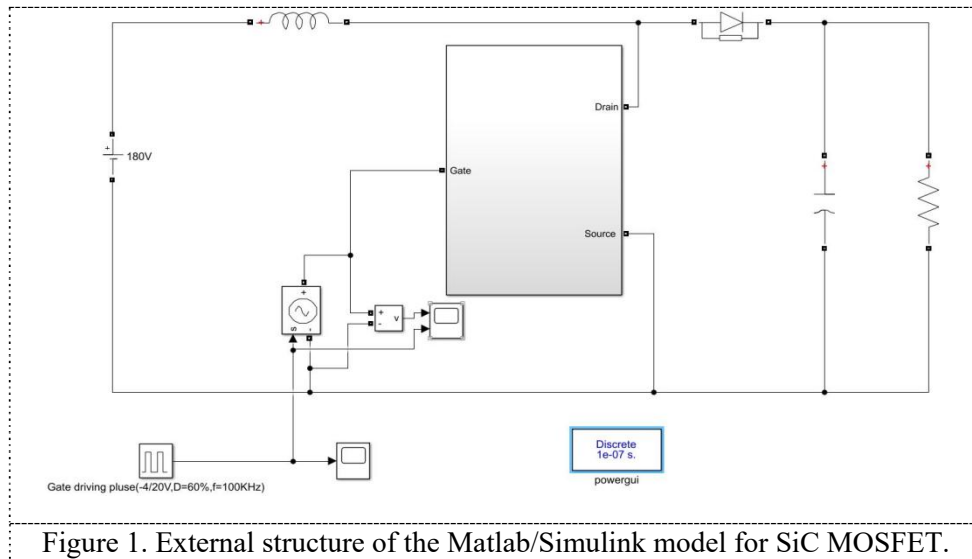


Figure 1. External structure of the Matlab/Simulink model for SiC MOSFET.

The threshold voltage of the MOSFET realized in the model depends on the temperature function, see the formula (5). The realization of static characteristics is calculated by formula (1-4). The calculation results of these two modules are input into the voltage control current source to realize the I of SiC MOSFET T_{ds} output. Instead of the nonlinear capacitance, the non-linear capacitance C_{gd} is found to V through actual analysis $V_{gd}=V_{gs}-V_{ds}$, And V_{gs} for V_{ds} the effect is too small to be negligible, so it can be considered as $V_{gd}=-V_{ds}$. Voltage controls current source G_{gd} See the fitting equation (6-7).

$$G_{gd} = \left(\frac{a}{\left(1 - \frac{V_{gd}}{b}\right)^c} - a \right) \frac{dV_{gd}}{dt}, V_{gd} \leq 0 \quad (6)$$

$$G_{gd} = 0, V_{gd} > 0 \quad (7)$$

Where: a, b, c is the internal parasitic capacitance fitting parameter, $a=18.096, b=0.2678, c=7.5277$. Based on the study of SiC MOSFET internal parasitic capacitance, the switching process of SiC MOSFET under ideal conditions was analyzed in the Matlab/Simulink simulation circuit of the Boost converter based on Figure 1.

4. Model validation

The results of fitting the transfer characteristic and the output characteristic curves are shown in Figures 2 and 3. As we can see, along with the changes of V_{gs} and V_{ds} , the characteristic curve is basically consistent with the data manual curve. It shows that the current source model can accurately describe the static characteristics of SiC MOSFET accurately.

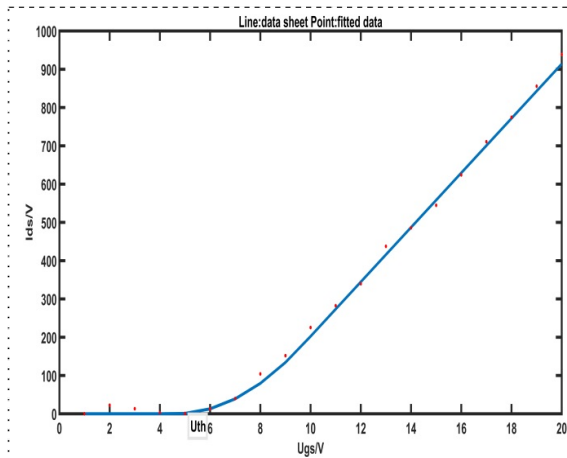


Figure 2. The transfer characteristic curve of the transfer property SiC MOSFET at 25°C.

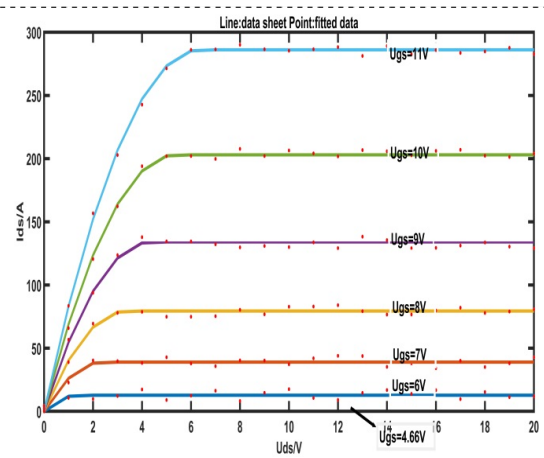


Figure 3. Output characteristic curve of SiC MOSFET at 25°C.

Figures 4 and 5 are the fitting results of parasitic capacitor C_{gd} in SiC MOSFET when we model C_{gd} . We always model C_{gd} by segmenting the gate-drain voltage. Therefore, our fitting curve is also a two-segment fit. The fitting curve can accurately show the nonlinear characteristics of C_{gd} . This shows that the model is accurate to describe the nonlinear capacitance characteristics.

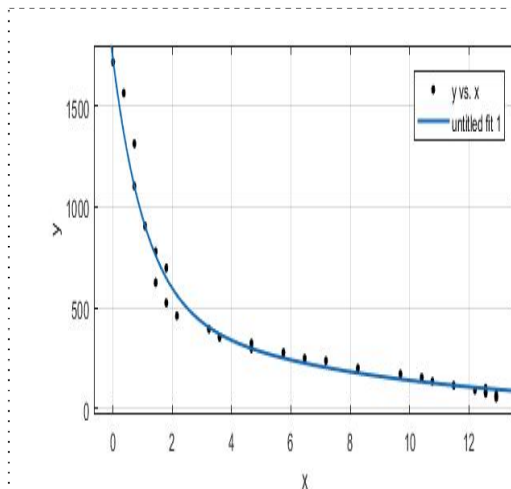


Figure 4. Capacitance C_{gd} to fit the curve.

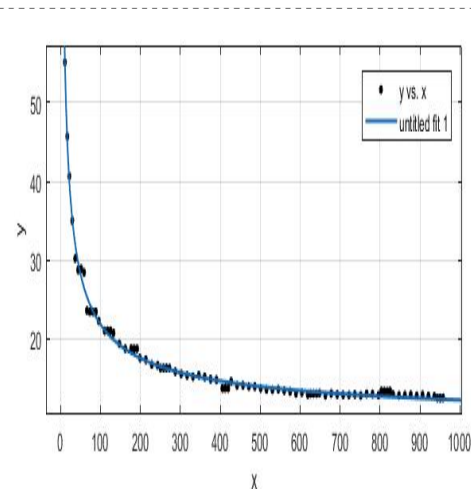


Figure 5. Capacitance C_{gd} to fit the curve.

Figures 6 and 7 are Waveform diagram of SiC MOSFET on and off time under $V_g=20V$, $V_{dc}=180V$, $R_g=2.5\ \Omega$, $T=25^\circ C$, respectively. In order to verify the dynamic characteristics of the model more intuitively, I also compared the simulated rise time and fall time with the values provided in the data manual. The opening time of simulation model and data manual model is 17.1ns and 18.4ns, and the error is 7%. The cut-off time of simulation model and data manual model is 12.7ns and 13.6ns respectively, and the error is 6.6%. By comparison, it can be seen that the simulation values are roughly the same as the standard values provided by the data manual. The model can realize the startup and shutdown process of SiC MOSFET well, which is beneficial to the application and simulation of SiC MOSFET of practical circuits.

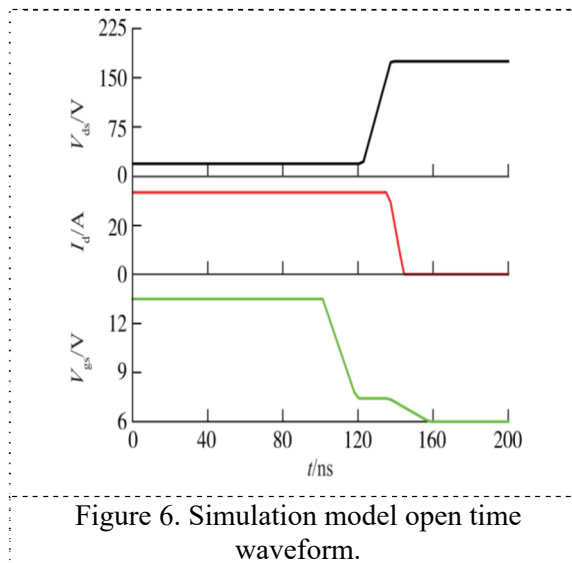


Figure 6. Simulation model open time waveform.

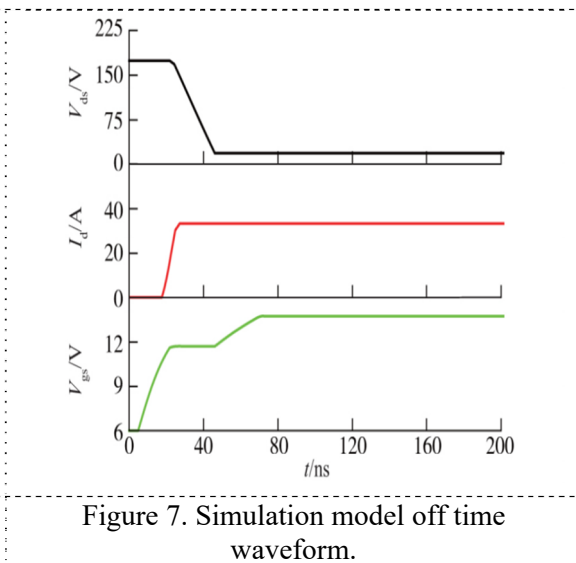


Figure 7. Simulation model off time waveform.

5. Conclusion

At present, the technology of SiC MOSFET is developing rapidly and it has a good prospect. It is becoming more and more popular in the fields of power conversion, transportation and so on. In this paper, a SiC MOSFET model is established in Matlab/Simulink environment by using Matlab/Simulink powerful mathematical processing ability and rich module functions. In addition, the accuracy of the model is verified by comparing the product receipt manual with the fitting data. In addition, the switch simulation waveform is roughly the same as the data manual waveform, and the error is controlled within 7%. This reduces the difficulty of modeling, and provides a new idea for establishing SiC MOSFET circuit simulation model in Matlab/Simulink.

Acknowledgment

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