SPICE-aided Modelling of SiC MESFETs

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Key words: SiC MESFETs, modelling, SPICE.

Abstract: In the paper the d.c. characteristics of the SiC MESFET operating in the wide temperature range are investigated. The transistor CRF24010 offered by Cree Inc. is considered. The characteristics obtained from measurements and SPICE simulations performed with the use of Raytheon-Statz model are compared.

Modeliranje SiC MESFET transistorjev s programom SPICE

Kjučne besede: SiC MESFET tranzistorji, modeliranje, SPICE

Izvleček: V prispevku raziščemo d.c. karakteristike SiC MESFET tranzistorja v širokem območju temperatur. Merili smo tranzistor CRF 24010 firme Cree Inc. in primerjali izmerjene vrednosti s tistimi, ki smo jih dobili s simulacijami s programom SPICE in Raytheon-Statz modelom.

1. Introduction

MESFETs are very popular high frequency devices (RF transistors) which have found applications in radiocommunication circuits, as: amplifiers, mixers, oscillators, etc. Commonly used MESFETs made of gallium arsenide (GaAs) are known since 1968. In 1998 the first MESFET made of silicon carbide (SiC MESFET) was worked out in Cree Labs., whereas since 2002 such devices have been commercially available /1/.

Computer-aided design of the circuits mentioned above, requires the credible, experimentally verified models of the considered devices, acceptable by proper computer tools, as e.g. SPICE /2/. The built-in SPICE models of a MESFET have been worked out for GaAs devices.

In the paper the usefulness of the built-in Raytheon-Statz model for describing SiC MESFETs is investigated. The estimation of accuracy of this model is performed by the comparison of the measured and simulated device characteristics. The transistor CRF24010 offered by Cree Inc. /3/ was chosen for investigations. In the Raytheon-Statz based simulations the values of the model parameters were obtained from measurements.

2. The Raytheon-Statz model

The network form of the Raytheon-Statz model is presented in Fig. 1 /2/.

The main device current i_D is of the form /2/:

- in the cut-off region (u_{GS}-VTO<0):

$$\mathrm{Idrain} = 0 \tag{1}$$

- in the linear and the saturation regions (u_{GS}-VTO≥0):

$$\mathrm{Idrain} = \mathrm{BETA} \cdot (1 + \mathrm{LAMBDA} \cdot u_{DS}) \cdot A \tag{2}$$

where: u_{GS} – the gate-source voltage, u_{DS} – the drain-source voltage, VTO – the pinchoff voltage, BETA – the transconductance coefficient, LAMBDA – the channel-length modulation coefficient, whereas the parameter A is given by /2/:

$$A = (u_{GS} - \mathrm{VTO})^2 \cdot \frac{K_t}{1 + B \cdot (u_{GS} - \mathrm{VTO})} \tag{3}$$

where: B – the doping tail extending parameter. In turn, the parameter K_t is given by the formula /2/:

- in the linear region:

$$0 < u_{DS} < \frac{3}{\mathrm{ALPHA}} \tag{4}$$

$$K_t = 1 - \left(1 - u_{DS} \cdot \frac{\mathrm{ALPHA}}{3}\right)^3 \tag{5}$$

- in the saturation region:

$$u_{DS} \geq \frac{3}{\mathrm{ALPHA}} \tag{6}$$

$$K_t = 1 \tag{7}$$

where: *ALPHA* – the saturation voltage parameter.

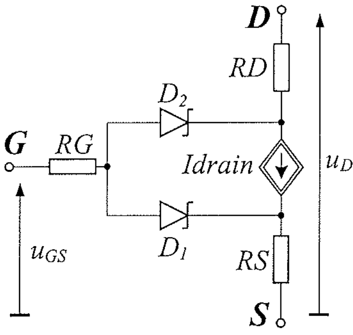


Fig. 1. The network form of the Raytheon-Statz model

The currents of the Schottky diodes (D_1 and D_2 in Fig. 1) are described by the ideal components only, expressed as follows /2/:

$$i_{GS} = IS \cdot \left[\exp\left(\frac{u_{GS}}{N \cdot Vt} \right) - 1 \right] \qquad (8)$$

$$i_{GD} = IS \cdot \left[\exp\left(\frac{u_{GD}}{N \cdot Vt} \right) - 1 \right] \qquad (9)$$

where: IS - the saturation current, N - the emission coefficient, Vt - the thermal potential.

In the model, the parameters: BETA, IS and VTO are dependent on the temperature T. The thermal dependence of BETA(T) and VTO(T) are given by /2/:

$$BETA(T) = BETA \cdot 1{,}01^{BETATCE \cdot (T - Tnom)} \qquad (10)$$

$$VTO(T) = VTO + VTOTC \cdot (T - Tnom) \qquad (11)$$

where: Tnom - the nominal temperature, VTOTC - the pinchoff voltage temperature coefficient, BETATCE - the transconductance exponential coefficient.

The thermal dependence of the saturation current IS(T) is given by /2/:

$$IS(T) = IS \cdot \exp\left[\frac{\left(\frac{T}{TNOM} - 1 \right) \cdot EG(T)}{N \cdot Vt} \right] \cdot \left(\frac{T}{TNOM} \right)^{\frac{XTI}{N}} \qquad (12)$$

where: XTI - the temperature exponent. The temperature dependence of the band-gap voltage (barrier height) is written in the formula /2/:

$$EG(T) = 1{,}16 - \frac{0{,}000702 \cdot T^2}{T + 1108} \qquad (13)$$

As it is seen, in the model under consideration, the temperature dependence of the band-gap energy Eq (13) is given just for the silicon (Si), therefore in the case of modelling transistors made of other semiconductors, e.g. gallium arsenide (GaAs), silicon carbide (SiC), Eq (13) is inaccurate.

3. The investigation results

To verify the Raytheon-Statz model, the current-voltage characteristics of CRF24010-101 SiC transistor in the wide temperature range were measured. The catalog admissible values of the parameters of the investigated device are given in Table 1 /3/.

TABLE 1. The catalog parameter values of CRF24010-101 transistor

Parameter	Catalog value
$U_{DS\,max}$	120 VDC
$U_{GS\,max}$	-20, +3 VDC
P_{max}	10W
f_{max}	2,7 GHz
$T_{j\,max}$	250 °C

The measured and simulated characteristics are shown in Figs. 2 - 7, where the points joined by the broken lines and the solid lines denote the measured and calculated results, respectively. The values of the model parameters are given in Table 2.

TABLE 2. The Raytheon-Statz model parameter values of CRF24010-101 transistor

Parameter	Value
VTO	-9,42 V
BETA	0,0136 A/V^2
LAMBDA	6,53 V^{-1}
ALPHA	0,136 V^{-1}
B	0,034 V^{-1}
VTOTC	-1,16mV/ °C
BETATCE	0,02 %/ °C
IS	7E-14 A
N	1,25

In Fig. 2 and 3 the transfer characteristics at U_{DS}=5V in the temperature range 295÷433K (Fig. 2) as well as at T=295K for two values of the drain-source voltage (Fig. 3) are presented. As seen, the value of the threshold voltage decreases with the increase of the temperature and the drain-source voltage. For u_{GS}<VTO the main current of the MESFET is of a relatively high value due to the current flowing through the Schottky diodes.

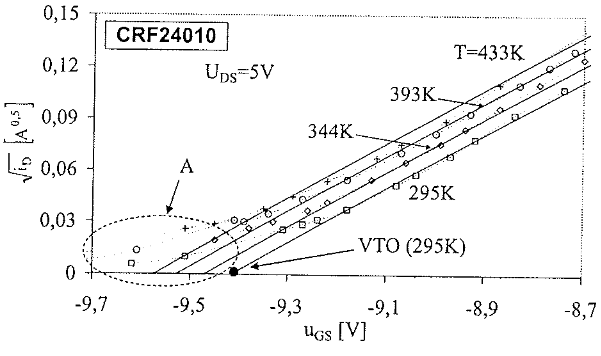


Fig. 2. The transfer characteristics at U_{DS}=5V

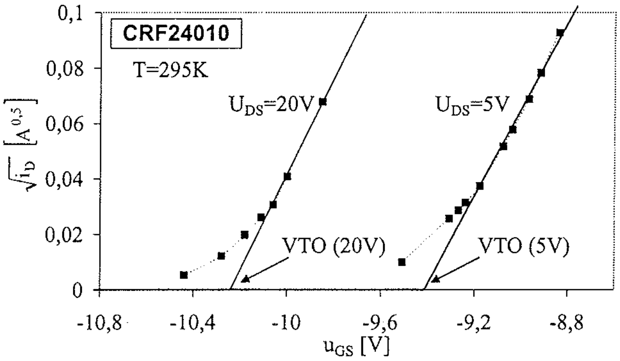


Fig. 3. The transfer characteristics at T=295K

The temperature dependence of the threshold voltage $V_{TO}(T)$ at two values of the drain-source voltage is presented in Fig. 4. As seen, these characteristics are quasi-linear and the temperature coefficients of changing V_{TO} are: VTOTC=-1,16mV/K at U_{DS}=5V and VTOTC=-0,68mV/K at U_{DS}=20V.

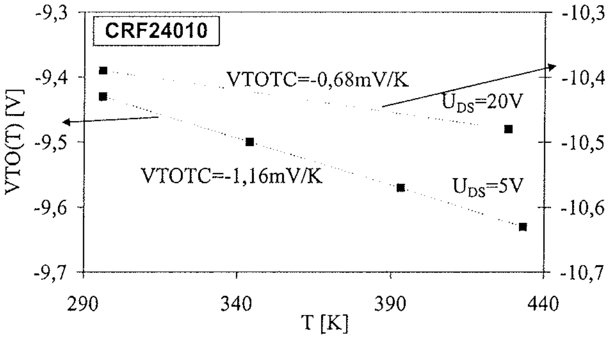


Fig. 4. The temperature dependence of the threshold voltage VTO(T)

In Fig. 5 the output characteristics in the range of the drain-source voltage up to 45V at the ambient temperature T=295K for two gate-source voltage values U_{GS}: -9V and -11V are shown. It is visible, that the acceptable agreement between simulation and measured results is observed at U_{GS}=-9V only. The value of the drain current corresponding to the characteristic measured at U_{GS}=-11V increases strongly, what probably results from influence of the drain-source voltage on the transistor threshold voltage (see Fig. 3).

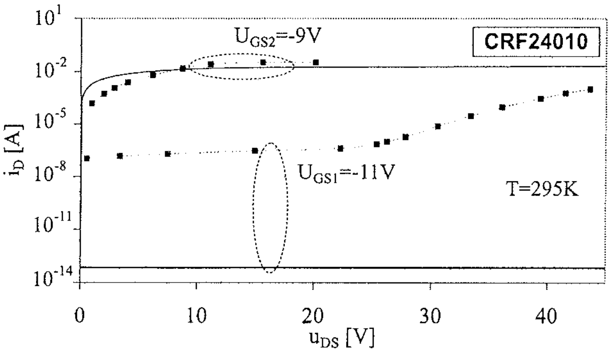


Fig. 5. The output characteristics at U_{GS}: -9V and -11V

In turn, in Fig. 6 the qualitative discrepancy between measurements and simulations in the avalanche range of the investigated device are observed. It should be noted, that at the point B (U_{DS}=110V) the transistor was damaged, in spite of that its operation point was inside SOA.

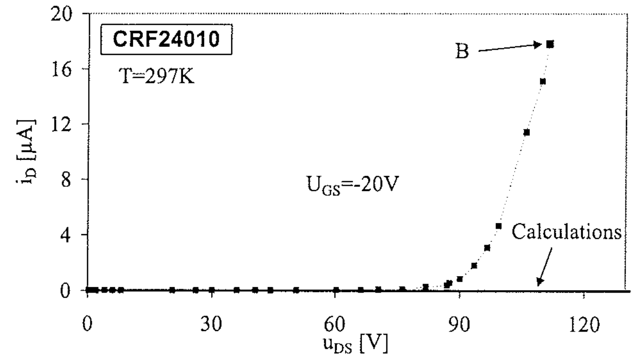
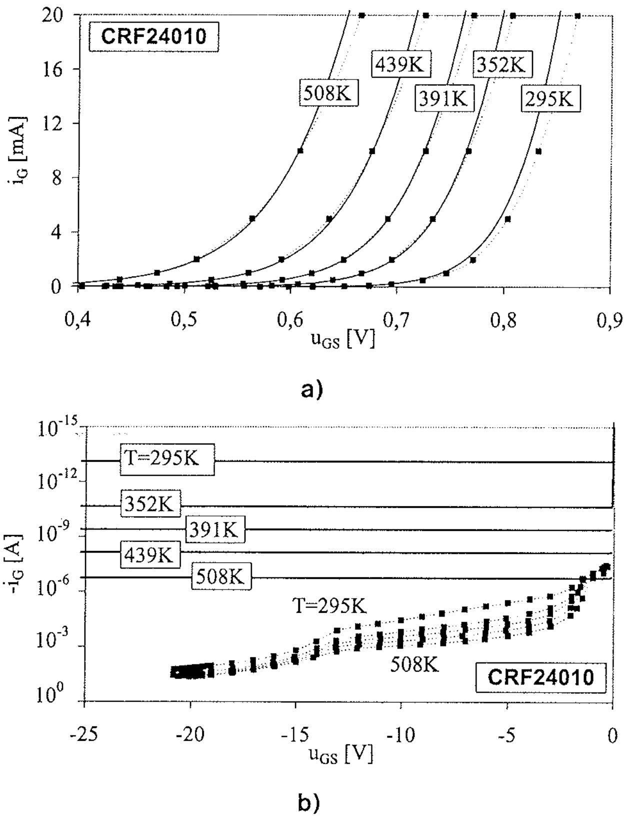


Fig. 6. The output characteristics at T=297K

In Fig. 7 the current-voltage characteristics of the Schottky diode (D_1) operating at the forward bias (Fig. 7a) and at the reverse bias (Fig. 7b), corresponding to five temperature values are presented.



a)

b)

Fig. 7. The characteristics of the Schottky diode D_1

As seen, the model fits well to measurements at the forward bias of the diode, whereas unacceptable discrepancies between theoretical and experimental results (differences higher then even 12 orders) occur at the reverse bias of the diode.

4. Conclusion

In the paper the usefulness of the Raytheon-Statz model for describing the SiC MESFET was estimated for the first time. The estimation of accuracy of the Raytheon-Statz model of the SiC MESFET (Cree Inc.) was performed by comparison of the measured and simulated characteristics in the wide range of the temperature.

The considered model takes into account the thermal dependences of: the pinchoff voltage, the saturation current and the band-gap energy. On the other hand, as seen from the investigation results (Figs. 2-7) to get the better agreement between measured and calculated characteristics, the dependencies: $V_{TO}(U_{DS})$, $U_{BR}(U_{GS},T)$ as well as the Schottky barrier lowering effect existing in the reverse biased diodes should be included in the considered model, which afterward could be implemented to SPICE as a subcircuit.

References

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/2/ "PSPICE A/D Reference Guide Version 10.0", Cadence Design Systems Inc., June 2003.

/3/ http://www.cree.com/products/pdf/crf24010.pdf.

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