Jarosław Kraśniewski
Włodzimierz Janke
Faculty of Electronics and Computer Sciences
Koszalin University of Technology, Poland

Calibration of temperature-sensitive parameter for Silicon Carbide SBD'S

Keywords: temperature-sensitive parameter calibration curves, Silicon Carbide Schottky Barrier diodes

1. Introduction

The junction temperature of semiconductor devices is the major factor influencing their parameters and characteristics. In the design process of power electronic circuit, the actual values of thermal resistance or thermal impedance of the devices have to be taken into account. The accurate value of the thermal resistance of a device for a given cooling conditions may be obtained by measurements. Standard methods of thermal resistance measurements consist of establishing the calibration curve of temperature-sensitive parameter and measuring the change of this parameter corresponding to the change of dissipated power. The proper calibration curves are measured in the temperature chamber, in the wide range of ambient temperature (T_a) and for the constant current value, which does not cause the self-heating phenomenon ($T_j \cong T_a$) [1]. Another possibility is to predict this curve theoretically or by simulations. If such prediction is sufficiently accurate, the measurements of thermal resistance would be a relatively simple task [2, 3].

The main purpose of presented work is to estimate the possibility of achieving the calibration curves without the measurements in the oven. The calibration curves has been obtained, on the basis of analytical equations or with the use of PSPICE simulations. The obtained curves has been compared with the curves measured in the standard way.

As an object of investigations the Schottky diodes manufactured by Cree and Infineon and MESFET transistors manufactured by Cree are chosen. The forward voltage drop on the m-s junction is chosen as a temperature-sensitive parameter.

The laboratory set-up for the measurement of the calibration curves is described in chapter 2, the method used for the theoretical curves calculation – in chapter 3.

The results of measurements and simulations are presented in chapter 4, and conclusions in chapter 5.

2. The laboratory SET-UP

In the measurements of the calibration curves, the diodes and transistors has been driven by the current I_M, small enough to avoid the self-heating phenomenon, which could influence of the temperature-sensitive parameter. The mentioned value depend on the allowable power for the considered semiconductor device and, in the presented case, has been setted as 1mA.

The measurement of the temperature-sensitive parameter (the forward voltage V_F for the diodes and the forward voltage V_{GS} on m-s junction for the MESFET transistors) is performed with the use of Agilent digital voltmeter 8½. The tested devices are fixed to the heat-sink with the dimensions: 110x126x136mm and such set-up is placed in the FEUTRON temperature oven. The internal temperature of the oven is additionally controlled with the use of of the Hart Scientific 1522 measure with the accuracy ±0.01°C ensured [4, 5, 6].

3. The Theoretically obtained calibration curves

The I-V characteristic of metal-semiconductor junction, for the relatively low values of forward current may be described by the equations [2]:

$$i \cong I_S \cdot \exp\frac{q \cdot V_F}{kT} \tag{1}$$

$$I_S = A \cdot T^{\chi} \cdot \exp\left(-\frac{q \cdot \Phi_B}{kT}\right) \tag{2}$$

where: k, q – physical constants, T – ambient temperature, Φ_B – junction barrier voltage, A – is a parameter dependent on junction area and Richardson constant. The value of χ parameter is approximately 2 for the m-s junction [2].

From equations (1) and (2), the dependence of the junction voltage on the temperature (at constant current) may be obtained:

$$V_F(T) = \phi_B + \frac{T}{T_O}(V_O - \phi_B) - \chi\frac{kT}{q} \cdot \ln\frac{T}{T_O} \tag{3}$$

where: V_O – the voltage accross the junction for the reference temperature T_O and current I_O.

According to the mentions in the literature [7] it may be assumed, that the most common metal in m-s junction for SiC elements is nickel or titan, and value of barrier voltage Φ_B for Ni is between 1.26 and 1.69eV and for Ti 0.8 to 1.13eV. On the basis of calibration curves obtained from analytical equations and informations available on internet, one is able to determine the type of metal used in m-s junction for investigated SiC devices.

4. The exemplary results

In this chapter, the exemplary calibration curves: measured, simulated in PSPICE and calculated analytically from Eqn. (3) for chosen SiC Schottky diodes and MESFET transistors are presented. In PSPICE simulations the parameter set published by manufacturer Cree is used [8].

For the junctions barrier voltage Φ_B estimation, 10 calibration curves for each type of devices obtained through measurements were used. The range of barrier voltage Φ_B for respective devices was as follows: for diodes – CSD01060 (Cree) from 0,86873 to 0,87279 eV, for CSD04060 (Cree) from 0,81112 to 0,82892 eV, for IDH04SG60C (Infineon) from 0,83625 to 0,84080 eV and for CRF24010 (Cree) transistor from 0,74474 to 0,79321 eV.

The results obtained for the Cree silicon carbide Schottky diodes are shown in Fig. 1 (CSD01060) and Fig. 2 (CSD04060).

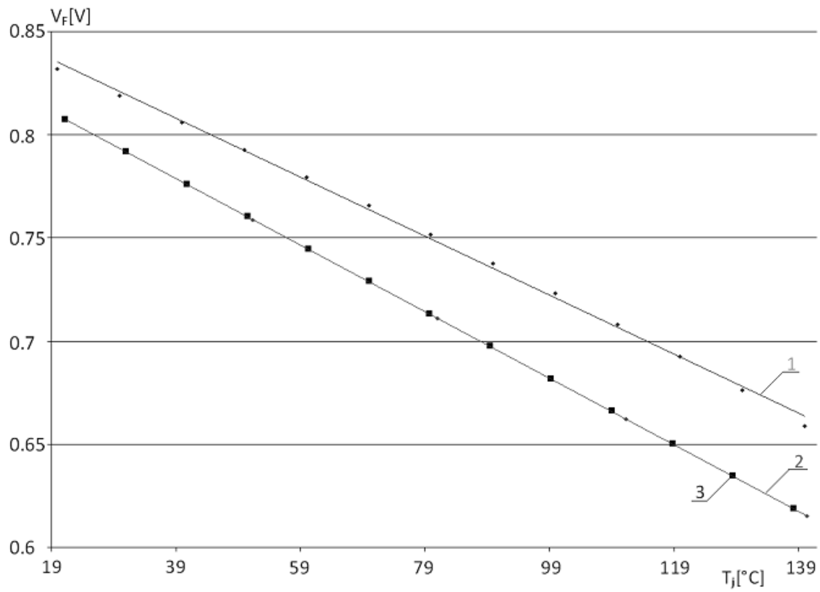

Fig. 1. The calibration curves $V_F(T_j)$ of Schottky SiC diode (CSD01060) 1 - model SPICE, 2 – measurement, 3 – theoretical, according to Egn. (2)

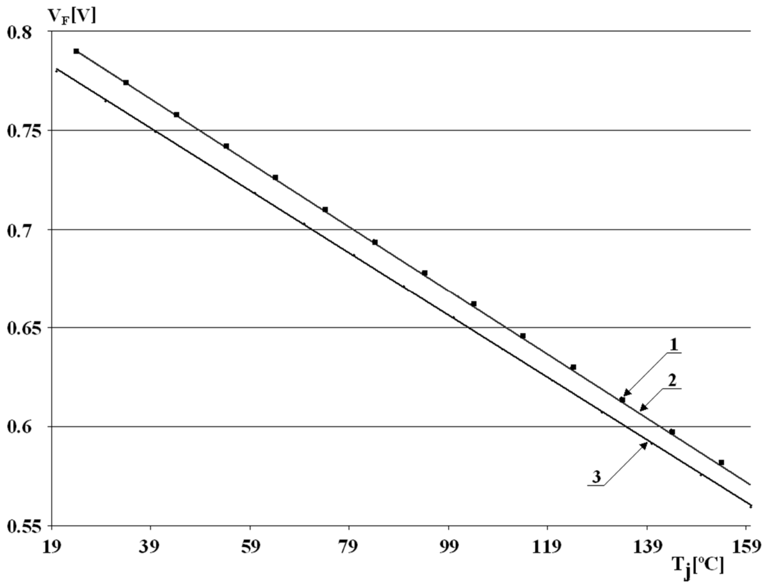

Fig. 2. Calibration curve $V_F(T_j)$ of Schottky SiC diode (CSD04060) 1 – theoretical, according to Egn. (2), 2- measurements, 3 – SPICE simulation

It may be observed, that the calibration curve obtained on the basis of the Eqn. (2) and the measured curve are in good conformity. Curves obtained through simulations (SPICE software) based on manufacturers model (Cree) differ substantially from measurement curves.

The results obtained for the Infineon silicon carbide Schottky diodes are shown in Fig. 3 (IDH04SG60C).

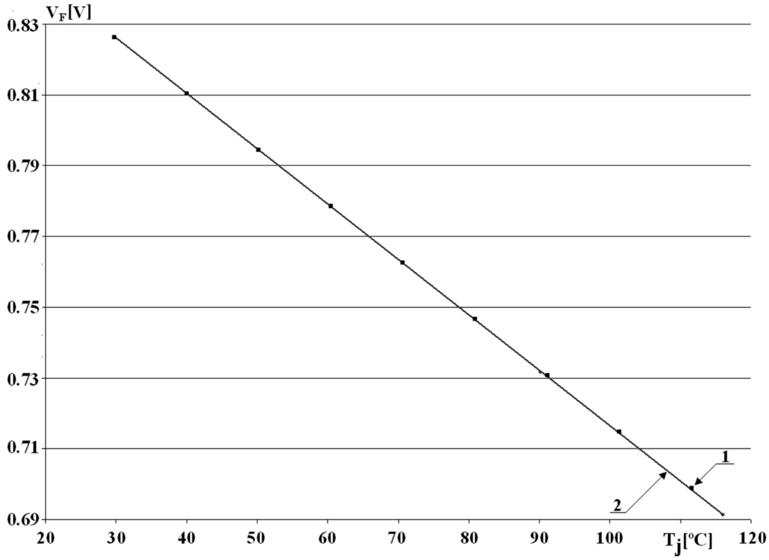

Fig. 3. Calibration curve $V_F(T_j)$ of Schottky SiC diode (IDH04SG60C) 1 – theoretical, according to Egn. (2), 2- measurements

The results obtained for the Cree silicon carbide transistor are shown in Fig. 4 (CRF24010).

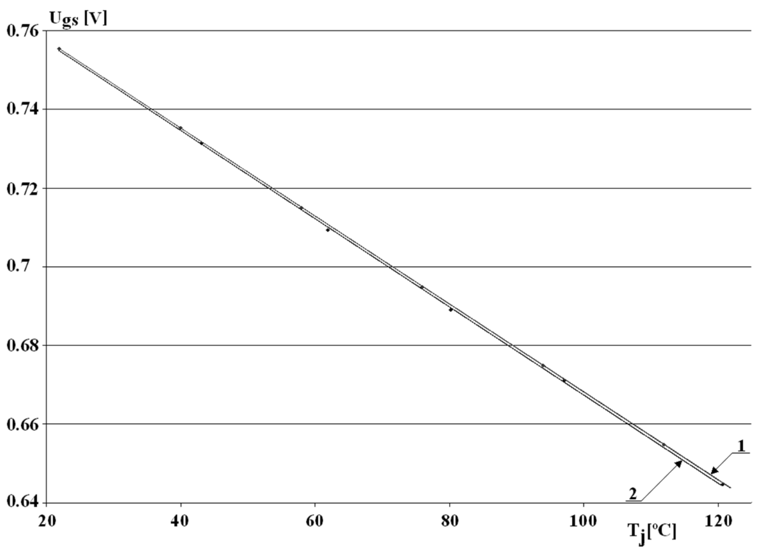

Fig. 4. Calibration curve $V_{GS}(T_j)$ of MESFET SiC transistor (CRF24010) 1 – theoretical, according to Egn. (3), 2- measurements

In the case of results from figures 3 and 4 no attempts to calculate calibration curves through the use of SPICE software were made, because manufacturer hasn't provided any models of corresponding devices. However, characteristics based on the theoretical models derived from dependency (3) show good consistency with calibration curves obtained through measurements.

5. Conclusions

The exemplary results of the measurements are presented in Figs 1÷4 and compared with the results of theoretical predictions and in the case of Figs 1÷2, of SPICE simulations. One may observe that the measurement results are better fitted to theoretical curve than to results of SPICE simulation.

The accuracy of calculation of the calibration curves with the use of Eqn. (3) depends on the properly chosen value of barrier voltage Φ_B. In this case, the theoretical curves are very similar to those obtained in the measurements. The value of Φ_B may be treated as a constant parameter for many types of Schottky diodes based, on the same set of metal (Ti) and semiconductor (SiC). The slightly different values of Φ_B observed in MESFET result probably form the difference of technological processes of SBD and MESFET based on SiC. The accurate prediction of the calibration curves and calculations of the internal devices temperature change based on them, is neccessary in the process of the measurements of thermal resistance or thermal impedance of a device in the real cooling conditions. Knowing the calibration curve of a given device, one is able to perform the measurements of thermal resistance or thermal impedance of it, without the use of temperature chamber.

References

1. P.M. Igic, P.A. Mawby, M.S. Towers and S. Batcup, Thermal model of power semiconductor devices for electro-thermal circuit simulations, INTERNATIONAL CONFERENCE ON MICROELECTRONICS, Vol 1, 12-15 MAY 2002, pp. 171-174.
2. W. Janke, Thermal Phenomena in Semiconductor Devices, WNT, Warszawa, 1992 (In Polish).
3. W. Janke, J. Kraśniewski, M. Kraśniewski, M. Oleksy, J. Mizeraczyk, M. Kocik, Measurements of thermal transients in semiconductor devices in the internal or external power excitation mode, IMAPS, Poland, 17-19 September 2003, pp. 177-180.
4. W. Janke, J. Kraśniewski, The investigations of transient thermal characteristics of microwave transistors, Metrol. Meas. Syst., vol. XVI (2009), no.3, pp. 433-442.

5. Department of defense MIL-STD-750D, Test method standard semiconductor devices, 28 Feb 1995.
6. EIA/JESD51, Methodogy for the Thermal Measurement of Component Packages (Single Semiconductor Device), Dec 1995 - Nov 2010.
7. S. Ferrero, F. Giorgis, C.F. Pirri, P. Mandracci, C. Ricciardi, L. Scaltrito, C. Sgorlon, G. Richieri, L. Merlin, Processes nad properties of 4H-SiC based Schottky diodes, CNR-MASPEC, March 2002 Parma.
8. PSpice Model - SiC Schottky Diode:
http://www.cree.com/products/power_docs.asp

Abstract

Thermal properties of semiconductor device may be characterized by thermal parameters or characteristics such as thermal resistance and thermal impedance. In order to calculate the thermal resistance or thermal impedance one must have a calibration curve of temperature-sensitive parameter of the device (e.g. the voltage drop across a junction).

For the obtaining the calibration curve by measurement, the temperature chamber has to be used. Another possibility is to predict this curve theoretically from analytical equations or by simulations (e.g. PSPICE).

In the paper, the simulation and theoretical predictions of temperature-sensitive parameter calibration curves are compared with the results of measurement for SiC devices with metal-semiconductor junction.

Streszczenie

Właściwości termiczne elementów półprzewodnikowych można charakteryzować poprzez parametry lub charakterystyki termiczne, takie jak rezystancja i impedancja termiczna. W celu wyznaczenia rezystancji lub impedancji termicznej elementu półprzewodnikowego musimy posiadać krzywą kalibracji parametru termoczułego (np. spadek napięcia na złączu).

Dla uzyskania pomiarowej krzywej kalibracyjnej należy wykorzystać komorę temperaturową. Inną możliwością jest teoretyczne przewidywanie ww. krzywej z równań analitycznych lub symulacji (np. PSPICE).

W niniejszej pracy porównano krzywe kalibracyjne parametru termoczułego otrzymane na drodze symulacji i teoretycznych obliczeń z wynikami pomiarów dla urządzeń SiC o złącze m-s.

Słowa kluczowe: krzywa kalibracyjna parametru termoczułego, dioda Schottky z węglika krzemu