Janusz ZARĘBSKI, Jacek DĄBROWSKI

Akademia Morska w Gdyni, Katedra Elektroniki Morskiej

Electrothermal Model of SiC Power Schottky Diodes

***Abstract**. The paper concerns the problem of modelling d.c. characteristics of commercial SiC power Schottky diodes with self-heating taken into account. The electrothermal model of the investigated devices is proposed and experimentally verified. The evaluation of accuracy of the elaborated model has been performed by comparison of measured and calculated characteristics of selected SiC power Schottky diodes.*

***Streszczenie.** Praca dotyczy problemu modelowania, z uwzględnieniem zjawiska samonagrzewania, prądowo-napięciowych charakterystyk komercyjnie dostępnych diod Schottky'ego mocy wykonanych z węglika krzemu. Zaproponowano i eksperymentalnie zweryfikowano elektrotermiczny model rozważanych w pracy elementów półprzewodnikowych. Ocenę dokładności modelu przeprowadzono poprzez porównanie charakterystyk obliczonych w programie SPICE z charakterystykami zmierzonymi wybranych diod Schottky'ego z węglika krzemu. (**Model elektrotermiczny diod Schottky'ego mocy wykonanych z węglika krzemu**)*

Słowa kluczowe: dioda Schottky'ego, węglik krzemu, modelowanie, samonagrzewanie.
Keywords: Schottky diode, silicon carbide, modelling, self-heating.

Introduction

Power Schottky diodes are very popular unipolar devices, often used in Switch Mode Power Supplies. The essential advantage of Schottky diodes is a low value of the capacitance (only junction capacitance exists), what results in high speed of the device switching. On the other hand the main drawback of the considered devices, especially made of silicon, is relatively low value of the breakdown voltage and a high value of the reverse current [1]. The improvement of properties of the considered power devices is possible by using wide band-gap materials, as: silicon carbide (SiC), gallium nitride (GaN) or diamond (C), in the fabrication process. Currently, due to advancement of technology, the most promising one is silicon carbide. Since 2001, 300 V and 600 V SiC power Schottky diodes manufactured by Infineon Technologies have been available on the market [2]. Since 2002 also Cree has been offering considered diodes of 1200 V blocking voltage [3]. The other manufacturers, for example TT electronics Semelab, STMicroelectronics and SemiSouth, also offer the SiC power Schottky diodes nowadays.

The important information about the device performances result from their d.c. characteristics. The shape of these characteristics depends on the temperature, especially the inner (junction) temperature of the higher value than the ambient one, due to self-heating phenomenon [4] resulting from change of the device dissipated thermal power into the heat at non-ideal cooling conditions. The characteristics considering the self-heating are named non-isothermal characteristics, in contrast with the isothermal ones (given in catalogues) corresponding to the ideal cooling conditions. The self-heating causes not only qualitative but also quantitative changing of the characteristics shape. For the reverse-biased devices operating in non-ideal cooling conditions ambiguous characteristics can be observed [5]. There is any point laying on such ambiguous characteristics, interpreted as the electrothermal breakdown point, at which the device differential resistance changes its sign from the positive to negative one. The important task is to include the considered phenomenon in the model of the Schottky diode.

In modelling, very important role is played by credible, experimentally verified compact models of semiconductor devices. The compact models allow to obtain good accuracy and short time of simulations. Commonly used device models are isothermal ones, valid only at a fixed value of the device temperature (the inner device temperature equals the ambient temperature). On the other hand, the electrothermal models (ETMs) including the self-heating are formulated as the connection of the electrical (isothermal) model and a thermal model describing dependence of the device inner temperature on the dissipated thermal power [4, 6]. In the process of analysis and designing electronic circuits, effective computer-tools are more and more frequently used. The most known are SPICE (especially PSPICE) and SABER. The first program possesses built–in models of semiconductor devices and ICs, including the silicon diode model along with library parameter values for a lot of devices [7, 8]. Moreover, in the second program modelling bases on language standards MAST and VHDL-AMS to describe the physical and behavioral properties and attributes of the semiconductor devices, as well as power electronics systems [9].

In the literature there are a lot of publications concerning of modelling and models of SiC power devices. Some part of them deals with the problem of modelling SiC power diodes, in particular SiC Schottky diodes, both with the use of SPICE and SABER, e.g. [10-15]. Unfortunately, research articles usual refer to devices under isothermal conditions. Sometimes such conditions are wrongly described as electrothermal, as e.g. in [10, 12], where temperature dependencies of the some parameters are presented only, without taking into account self-heating phenomenon influence. Very often models are experimentally verified at one ambient temperature only, as e.g. in [14, 15], or for one type of polarization as in [11]. Moreover, the models proposed in the literature hardly ever are tested for commercial diodes. For example, in the paper [13] the JBS (Junction Barrier Schottky) rectifier model is presented, but its accuracy for reverse biased diodes made by Infineon Technologies is not large.

However, on the other hand one should be mention, that the SPICE built–in isothermal model of the diode is very popular, and as an example Cree Research make accessible this model parameter values for SiC Schottky diodes at the company web site [16]. Next, other semiconductor manufacturers make their own models of semiconductor devices. For instance, Infineon Technologies has formulated ETM designed for modelling of its own SiC Schottky diodes [17]. Unfortunately, as the preliminary authors investigations were proved [18, 19], the accuracy of the models of the investigated class of semiconductor devices used for modelling in SPICE, is unsatisfactory. So, there is need to formulate the relatively simple electrothermal model of the SiC power Schottky diodes with acceptable accuracy, including self-heating, appropriated for the SPICE computer program.

In the paper the electrothermal model of the commercial silicon carbide power Schottky diodes is presented. This model was formulated in the form of the subcircuit for PSPICE [7]. The experimental verification of the ETM is performed by comparison of results of d.c. simulations and measurements of selected SiC power Schottky diodes.

Model form

The network form of the electrothermal model of the SiC power Schottky diode worked out by the authors is of the form shown in Figure 1. As seen, the elaborated ETM consists of the electrical (isothermal) model situated between the points A (anode) and C (cathode), the thermal model in which the potential value of the TJ node corresponds to the diode inner temperature, and the thermal power model, where the current of the controlled source GP is equal to the thermal power dissipated in the diode.

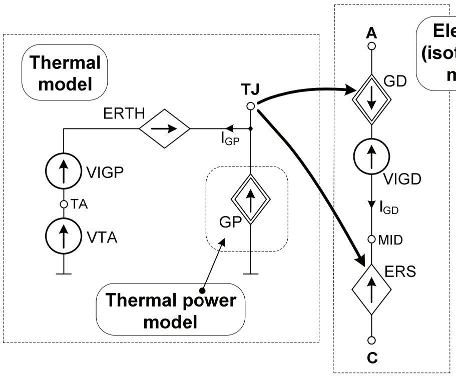

Fig. 1. Network form of the electrothermal model of the power SiC Schottky diode

The isothermal model consists of three elements, where the controlled current source GD describes the main d.c. current of the diode, the controlled voltage source ERS models the diode series resistance, and the independent voltage source VIGD of the voltage equal to zero, which plays a role of the meter of the current of the controlled source GD.

The current of the source GD is described by the expression [20]:

$$I_{GD}(u,T_j)=ID(u,T_j)\cdot KLOW(u,T_j)+IGEN(u,T_j)+ \\ -IBR(u,T_j) \tag{1}$$

where T_j – the inner diode temperature, u – voltage between A and MID nodes, ID denotes the thermionic emission current [21], $KLOW$ determines the Schottky barrier lowering effect [21], $IGEN$ denotes generation current for the reverse range, whereas IBR denotes the avalanche phenomenon current.

The thermionic emission current is expressed by the formula [20]:

$$ID(u,T_j)=S\cdot A_R\cdot T_j^i\cdot exp\left(-\frac{B}{T_j}\right)\cdot\left[exp\left(\frac{q\cdot u}{k\cdot T_j\cdot N(u,T_j)}\right)-1\right] \tag{2}$$

where

$$B=\frac{q\cdot\phi_B}{k} \tag{3}$$

In equations (2) and (3) following notations are used: S – the device area, A_R – the Richardson's constant, i – the temperature index (for the ideal diode $i = 2$), B – the constant proportional to the barrier height ϕ_B, expressed in Kelvins, q is the electron charge, k denotes the Boltzmann's constant, whereas $N(u,T_j)$ denotes the emission coefficient. This coefficient is given by the equation [20]:

$$N(u,T_j)=\begin{cases} NF\cdot\begin{pmatrix}1+TNF1\cdot(T_j-T_O)\\ +TNF2\cdot(T_j-T_O)^2\end{pmatrix} & for\ \ u\geq 0\\ NR & for\ \ u<0\end{cases} \tag{4}$$

where NF is the parameter for the forward biased diode, $TNF1$ and $TNF2$ are the temperature coefficients of NF parameter, NR describes the reverse biased diode, whereas T_O is the reference temperature.

The Schottky barrier lowering effect occurring in the reverse biased diode is described by the exponential function with parameters k_{SCH} and p [20]:

$$KLOW(u,T_j)=exp\left(\frac{k_{SCH}\cdot\sqrt[4]{|u|^p}}{T_j}\right) \tag{5}$$

The generation current is given by the following expression [20]:

$$IGEN(u,T_j)=KGEN\cdot(|u|+1V)^{1/2}\cdot T_j^{\,g}\cdot exp\left(\frac{-BGEN}{T_j}\right)\cdot \\ \cdot\left[exp\left(\frac{q\cdot u}{k\cdot T_j\cdot N(u,T_j)}\right)-1\right] \tag{6}$$

where *KGEN* is the coefficient of the generation phenomenon, *g* is the temperature index (for the ideal diode $g = 1.5$), and *BGEN* corresponds to the barrier height for considered current, expressed in Kelvins.

The avalanche breakdown current is described by the following formula [20]:

$$IBR(u,T_j)=IB\cdot exp\left(\frac{(-BRV(T_j)-u)\cdot q}{k\cdot T_j\cdot NBR\cdot(1+TNBR\cdot(T_j-T_O))}\right) \tag{7}$$

where $BRV(T_j)$ denotes the temperature dependence of the breakdown voltage of the form:

$$BRV(T_j)=BRVV\cdot(1+TBRVV\cdot(T_j-T_O)) \tag{8}$$

In equation (7) IB represents the current at $BRVV$ parameter, which is the isothermal breakdown voltage corresponding to the reference temperature T_O, parameter NBR describes the slope of the avalanche characteristics, and $TNBR$ is the temperature coefficient of NBR parameter, whereas in (8) $TBRVV$ is the temperature coefficient of the breakdown voltage.

The voltage on the controlled source ERS is described by the expression [20]:

$$U_{ERS}=I_{VIGD}\cdot RS(T_j) \tag{9}$$

where $RS(T_j)$ is the diode series resistance dependent on the temperature, whereas I_{VIGD} is the current of the zero voltage source VIGD.

The diode series resistance is given by the following equation [20]:

$$RS(T_j)=RSW\cdot\left(1+TRS1\cdot(T_j-T_O)+TRS2\cdot(T_j-T_O)^2\right) \tag{10}$$

where RSW is the diode series resistance at the reference temperature, and $TRS1$, $TRS2$ are the temperature coefficients of the diode resistance.

The thermal model (see Fig. 1) describes the relation between the inner device temperature T_j and the thermal power P_H dissipated in the Schottky diode. The ambient temperature value is determined by the potential value of the node TA, whereas the independent voltage source VIGP plays a role of the meter of the thermal power.

The controlled voltage source ERTH models the thermal resistance between the junction and the ambient, dependent on the thermal power dissipated in the diode and the ambient temperature. The voltage existing on the controlled source ERTH is described by [20]:

$$U_{ERTH} = LIMIT\left(\left(RTH \cdot \left(1 - k_{RTH} \cdot \left(T_a - T_O\right)\right) - \left(\alpha \cdot log\left(\frac{I_{VIGP}}{1A}\right)\right)\right), 0, \beta\right) \cdot I_{VIGP} \tag{11}$$

where I_{VIGP} is the current corresponding to the thermal power P_H and flowing trough the zero voltage source VIGP, $LIMIT$ denotes the SPICE standard function, RTH is the junction–ambient thermal resistance measured at the thermal power equal to 1 W in the reference temperature T_O, T_a is the ambient temperature, whereas k_{RTH}, α and β are the model parameters.

In the thermal power model the current flowing through the controlled source GP is described by the formula [20]:

$$I_{GP}\left(u, T_j\right) = I_{VIGD} \cdot u\left(A, C\right) \tag{12}$$

where $u(A,C)$ is the voltage between A and C nodes.

Measuring set of the thermal resistance

The equation (11) from previous chapter was determined from the measurements of the thermal resistance carried out in the special measuring set designed by the authors [22]. The block diagram of the measuring set is shown in Figure 2. It consists of two basic elements. The first element is the Schottky diode bias circuit, whereas second element is the microcomputer, which contains the analog/digital converter and the control and driving programmes. The analog/digital converter measures the thermo-sensitive parameter – the forward voltage drop across the metal-semiconductor junction.

The measuring method includes three steps. In the first step the calibration of the characteristics $u_f(T_a)$ of the forward biased Schottky junction for the small forward current I_m is carried out. In this step the inner temperature $T_j \approx T_a$ and from the appropriate formula the parameter $\gamma_u = du_f/dT_a$ for I_m current is calculated. In the second step the investigated diode is activated by the thermal power P_H until thermal steady state is achieved; then $T_j > T_a$. In the third step the thermal power is turn off and measuring set measures the voltage across Schottky junction at the current I_m until the thermal steady state is achieved, i.e. $T_j \approx T_a$.

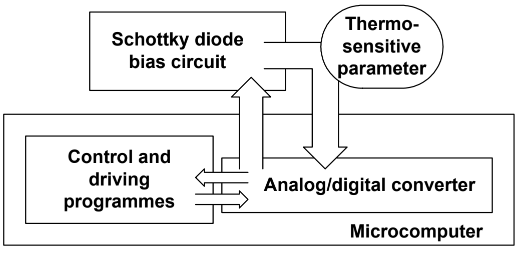

Fig. 2. Block diagram of the measuring set

The thermal resistance R_{th} is calculated from [22]:

$$R_{th} = \frac{-\left(u_f(t_{off}) - u_f(t \to \infty)\right)}{\gamma_u \cdot P_H} \tag{13}$$

where $u_f(t_{off})$ is the diode voltage at the moment the thermal power is turned off, whereas $u_f(t \to \infty)$ is the diode voltage at the thermal steady state.

As an example in Figure 3, the results of measurements of the thermal resistance of the SiC power Schottky diodes, SDP10S30 [23] and CSD10030 [3], made by Infineon Technologies and Cree Research, respectively, obtained by means of the presented measuring set, are shown. The measurements have been performed at different values of the thermal power and the ambient temperature. As seen, the values of the thermal resistance decrease with increase both the thermal power and the ambient temperature.

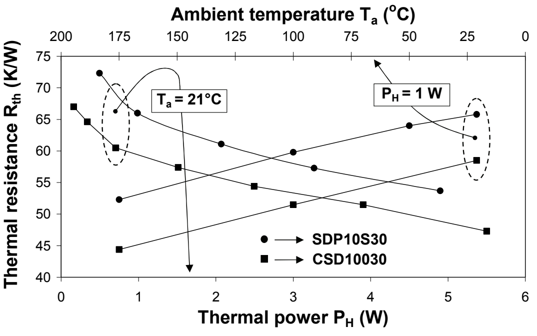

Fig. 3. Dependence of the thermal resistance of the SiC Schottky diodes with the thermal power and the ambient temperature

Measurements and simulations results of d.c. characteristics

To verify the accuracy of the proposed model, the d.c. non-isothermal characteristics of the diode CSD10030 and diode SDP10S30 were measured and compared to the PSPICE simulations. The diode CSD10030 was operated without and with the heat-sink, and the values of the measured thermal resistance RTH of the diode are equal to 57 K/W and 38 K/W, respectively. In turn, the diode SDP10S30 was operated without the heat-sink only, and for this device the parameter value of RTH is equal to 61 K/W. The proposed model was implemented in PSPICE as a subcircuit of the form of the file with *.cir* extension.

To obtain a good agreement between the results of numerical analysis and the measurements of the investigated devices, the estimation of parameters existing in the elaborated model had to be performed. The values of the thermal and electrical model parameters of the diodes CSD10030 and SDP10S30 are given in Table 1 and Table 2, respectively. The electrical parameter values of the ETM were obtained from measured d.c. characteristics of the diodes with the use of the proper procedure of the parameters estimation worked out by the authors [22]. The values of the thermal parameters existing in (11) were obtained from measurements of the thermal resistance carried out in the measuring set, described in previous chapter.

The results of the investigations of the considered diodes in the wide range of temperature changes are presented in Figures 4 and 5 – the forward range, and Figures 6 and 7 – the reverse range, respectively. In these figures points denote the non-isothermal measurements, and the thick lines represent calculation results performed by SPICE with the use of the elaborated ETM. Note, that the non-isothermal measurements have been performed in the thermal steady-state, therefore each point on the characteristics was measured relatively long time (typically after a few hundred seconds). The thin lines in Figures 4 and 6 denote the calculation results performed by the isothermal SPICE built-in diode model with the use of the available library parameter values given by Cree Research [16]. In turn, in Figures 5 and 7 the thin lines denote the calculation results performed by the ETM proposed by Infineon Technologies.

Table 1. The parameter values of the elaborated model for SiC Schottky diode CSD10030 (Cree Research)

Parameter [unit]	Value	Parameter [unit]	Value	
B [K]	10500	*TRS1* [K^{-1}]	0.00159	
S [cm^2]	0.0009	*TRS2* [K^{-2}]	$3.13 \cdot 10^{-5}$	
A_R [A/cm^2·K^2]	146	*TNF1* [K^{-1}]	$1.23 \cdot 10^{-4}$	
RSW [mΩ]	46.4	*TNF2* [K^{-2}]	$-2.18 \cdot 10^{-6}$	
NF	1.027	*i*	2	
BRVV [V]	160	*g*	1.5	
NR	1	*TBRVV* [K^{-1}]	-0.003	
k_{SCH} [K/V$^{p/4}$]	62	*TNBR* [K^{-1}]	-0.0025	
p	2.4	*RTH* [K/W]	57	38
BGEN [K]	4730	α [K/W]	14	0
KGEN [A/V^{½}·K^9]	$9 \cdot 10^{-7}$	k_{RTH} [K^{-1}]	0.002	
IB [A]	$0.01 \cdot 10^{-6}$	β [K/W]	75	
NBR	1400	T_O [K]	294	

Table 2. The parameter values of the elaborated model for SiC Schottky diode SDP10S30 (Infineon Technologies)

Parameter [unit]	Value	Parameter [unit]	Value
B [K]	15050	*TRS1* [K^{-1}]	0.0022
S [cm^2]	0.0212	*TRS2* [K^{-2}]	$1.6 \cdot 10^{-5}$
A_R [A/cm^2·K^2]	146	*TNF1* [K^{-1}]	0
RSW [mΩ]	49.1	*TNF2* [K^{-2}]	0
NF	1	*i*	2
BRVV [V]	330	*g*	1.5
NR	1200	*TBRVV* [K^{-1}]	-0.00085
k_{SCH} [K/V$^{p/4}$]	240	*TNBR* [K^{-1}]	-0.0025
p	1.8	*RTH* [K/W]	61
BGEN [K]	7880	α [K/W]	19
KGEN [A/V^{½}·K^9]	0.00025	k_{RTH} [K^{-1}]	0.0015
IB [A]	$0.03 \cdot 10^{-6}$	β [K/W]	75
NBR	1550	T_O [K]	300

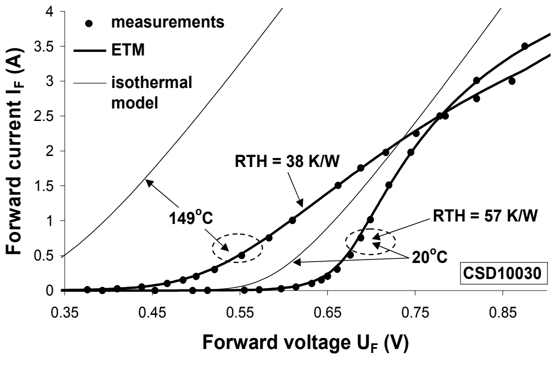

Fig. 4. The forward current-voltage characteristics of the SiC Schottky diode CSD10030

As seen in Figure 4, the non-isothermal characteristics corresponding to two values of the ambient temperature much differ from the isothermal ones.

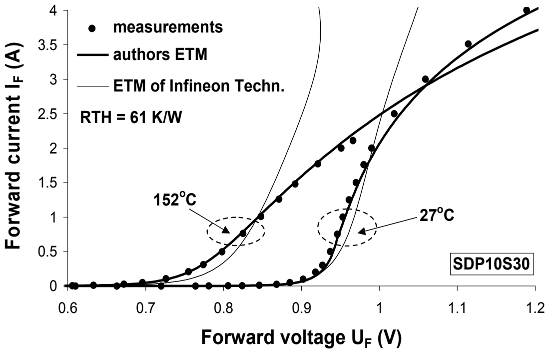

Fig. 5. The forward current-voltage characteristics of the SiC Schottky diode SDP10S30

Next, in Figure 5 the simulation results based on the Infineon's model differ considerably from the measurements. As seen, the presented ETM assures a very good agreement between calculations and measurements of the investigated silicon carbide Schottky diodes, and the error of the forward current estimation at the given voltage is not greater than a few per cent.

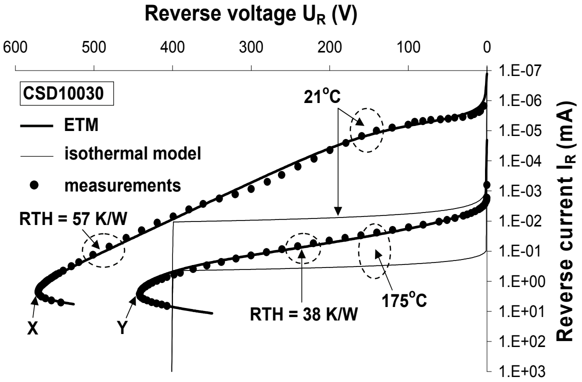

Fig. 6. The reverse current-voltage characteristics of the SiC Schottky diode CSD10030

Next, as seen in Figure 6 the non-isothermal characteristics corresponding to the reverse biased Schottky diode CSD10030 much differ from the isothermal ones, whereas the calculation results based on the authors model and the measured characteristics fit very well. On the investigated non-isothermal characteristics there are points (X and Y) interpreted as the electrothermal breakdown points, at which the device differential resistance changes its sign from the positive to negative one.

A very good agreement between the measurements and simulations performed with the use of model elaborated by the authors has been obtained also for the reverse biased diode SDP10S30. As seen in Figure 7, the characteristics calculated with the use Infineon's ETM show electrothermal breakdown phenomenon, while in the diode SDP10S30 this phenomenon is not observed, even at T_a = 175°C.

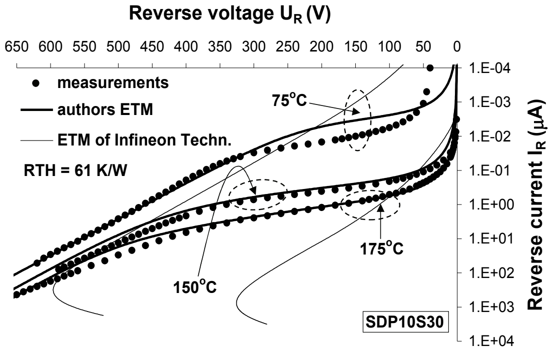

Fig. 7. The reverse current-voltage characteristics of the SiC Schottky diode SDP10S30

In the next two figures the relationships between the case temperature and the forward biased voltage of the investigated silicon carbide devices are presented. In Figures 8 and 9 the results of the measurements are denoted by points and the results of the simulations performed by authors ETM are denoted by thick lines. Additionally, in Figure. 9, the thin lines represent the results of simulations performed by ETM of Infineon Technologies. Note, that the case temperature T_c is obtained from:

$$T_c = T_j - P_{ths} \cdot R_{thj-c} \tag{14}$$

where P_{ths} is the thermal power dissipated in the diode obtained from simulations and R_{thj-c} is the value of the diode thermal resistance between the junction and the case (equal to 1.9 K/W in the catalogue of diode CSD10030 [3] and equal to 2.3 K/W in the catalogue of diode SDP10S30 [23]).

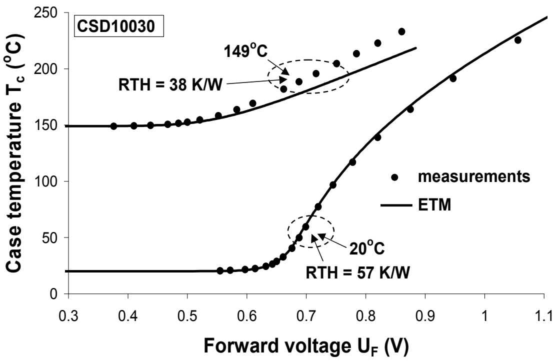

Fig. 8. The case temperature versus forward voltage across the SiC Schottky diode CSD10030

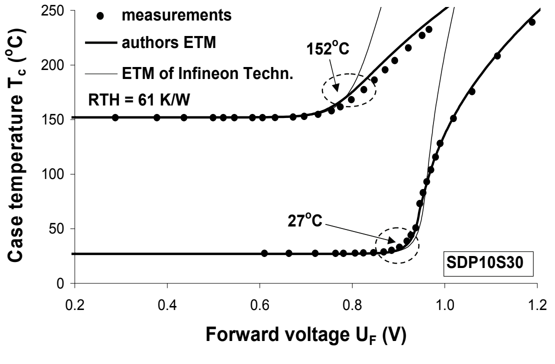

Fig. 9. The case temperature versus forward voltage across the SiC Schottky diode SDP10S30

As seen in Figures 8 and 9, the calculation results based on the ETM proposed by the authors and the measured characteristics fit well, and the relative error of the case temperature estimation is not greater than 10%.

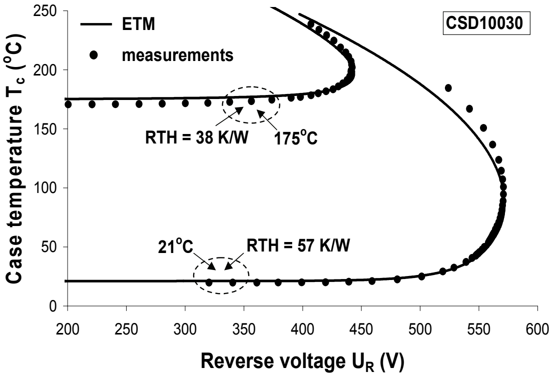

Fig. 10. The case temperature versus reverse voltage across the SiC Schottky diode CSD10030

The following Figure 10 shows the relationships between the case temperature and the reverse biased voltage of the diode CSD10030. Once again, even at electrothermal breakdown the compatibility between measurements and results of simulations obtained from the authors ETM is very satisfy.

One should notice, that the electrothermal breakdown point is described by three coordinates: the breakdown voltage u_t, the breakdown current i_t at u_t voltage, and the inner critical temperature T_{jt}. To estimate the correctness of the proposed ETM in calculation of the critical inner temperature of the Schottky diode at the breakdown point, in Table 3 for diode CSD10030 the values of T_{jt} calculated by ETM and obtained from experiment are compared at two ambient temperatures T_a. In the last case, after the measurements of the coordinates of the breakdown point, i.e. voltage u_t and the current i_t, the temperature T_{jt} is obtained from:

$$T_{jt} = T_{cjt} + u_t \cdot i_t \cdot R_{thj-c} \tag{15}$$

where T_{cjt} is the measured diode case temperature.

As results from Table 3, the proposed ETM ensures a good accuracy of estimation of the temperature T_{jt}, especially at higher ambient temperature. For example, at T_a = 175°C the difference between calculations by ETM and experiment is less than 3%. In turn, at lower ambient temperature (T_a = 21°C) the error of estimation of T_{jt} by ETM is still acceptably low (8%).

Table 3. The values of the critical temperature T_{jt} for diode CSD10030

	Critical temperature T_{jt} [°C]	
	T_a = 21°C	T_a = 175°C
Measurements	96.9	204.2
Simulations by ETM	89.3	199.1

Conclusions

In the paper it has been shown, that the properties of silicon carbide power Schottky diodes significantly depend on the self-heating phenomenon. Moreover, the value of the thermal resistance depends on both the thermal power dissipated in the diode and the ambient temperature.

The new elaborated electrothermal model of the SiC power Schottky diodes makes possible to evaluate the influence of thermal phenomena on properties of the investigated devices. This model is very accurate and can be use in practice, especially in designing of electronic circuits comprising SiC power Schottky diodes.

REFERENCES

[1] Benda, V.; Gowar, J.; Grant, D.A.: *Power Semiconductor Devices – Theory and Applications*. John Wiley & Sons Ltd., 1999.

[2] Zverev, I.; Treu, M.; Kapels, H.; Hellmund, O.; Rupp, R.: *SiC Schottky Rectifiers: Performance, Reliability and Key Applications*. EPE Conf. Proc., Graz, August 2001.

[3] http://www.cree.com/products/power_docs.htm.

[4] Zarębski, J.: *Modelling, Simulations and Measurements of Electrothermal Course in Semiconductor Devices and Electronic Circuits* (in Polish). Maritime Academy in Gdynia, Poland, 1996.

[5] Stepowicz, W.J.: *Unified Approach to Breakdown Phenomena in Silicon P-N Junction*. Solid-State Electronics, Vol. 22, No. 1-B, 1979, pp. 15-19.

[6] Hefner, A.R.; Blackburn D.L.: *Simulating the Dynamic Electrothermal Behavior of Power Electronic Circuits and Systems*. IEEE Transactions on Power Electronics, Vol. 8, No. 4, October 1993, pp. 376-385.

[7] PSpice Reference Guide, Product Version 10.0, June 2003, pp. 146-151.

[8] Shur, M.: *Introduction to Electronic Devices*. John Wiley & Sons, Inc., 1996.

[9] http://www.analogy.com/Tools/SLD/Mechatronics/Saber/Pages/CapModeling.aspx.

[10] Kolessar, R.; Nee, H.P.: *An Experimentally Validated Electro-thermal Compact Model for 4H-SiC Power Diodes*. ISIE Proc., Pusan-Korea, June 2001, pp. 1345-1350.

[11] McNutt, T.; Hefner, A.; Mantooth, A.; Duliere, J.; Berning, D.; Singh, R.: *Silicon Carbide PiN and Merged PiN Schottky Power Diode Models Implemented in the Saber Circuit Simulator*. PESC Proc., Vol. 4, 2001, pp. 2103-2108.

[12] Hernandez, L.; Claudio-Sanchez, A.; Cotorogea, M.; Aguayo, J.; Rodriguez, M.A.: *4H-SiC PiN Diode Electrothermal Model for Conduction and Reverse Breakdown for Pspice Simulator*. CIEP Proc., Morelos, August 2008, pp. 192-197.

[13] Zhu, L.; Chow, T.P.: *Analytical Modeling of High-voltage 4H-SiC Junction Barrier Schottky (JBS) Rectifiers*. IEEE Transactions on Electron Devices, Vol. 55, No. 8, August 2008, pp. 1857-1863.

[14] Tayel, M.B.; El-Shawarby, A.M.: *A Self-consistent Modeling of 4H-SiC Schottky Barrier Diodes*. IWPSD Proc., December 2007, pp. 138-141.

[15] Zhang, H.; Tolbert, L.M.; Ozpineci, B.: *System Modeling and Characterization of SiC Schottky Power Diodes*. IEEE COMPEL Proc., NY, USA, July 2006, pp. 199-204.

[16] http://www.cree.com: CPWR-PSPICE Rev-A.zip/CREE Schottky.lib – parameters values library of the SPICE built-in diode model.

[17] http://www.infineon.com: Psice_SiC_L3_2.zip.

[18] Zarębski, J.; Dąbrowski, J.; Bisewski, D.: *The Analysis of Temperature Influence on Switching Behaviour of the Power Schottky Diodes* (in Polish). Electronics, No. 2, 2007, pp. 18-20.

[19] Zarębski, J.; Dąbrowski J.: *D.C. Characteristics of SiC Power Schottky Diodes Modelling in SPICE*. Informacije MIDEM, Vol. 36, No. 3, September 2006, pp. 123-126.

[20] Zarębski J.; Dąbrowski J.: *Non-isothermal Characteristics of SiC Power Schottky Diodes*. International Symposium on Power Electronics, Electrical Drives, Automation and Motion SPEEDAM 2008, June, Italy, pp. 1363-1367.

[21] Sze, S.M.: *Physics of Semiconductor Devices*. John Wiley & Sons, Inc., 1996.

[22] Dąbrowski, J.: *Modelling of Power Schottky Diodes with Thermal Effects Taken into Account* (in Polish). Doctor's thesis, Technical University of Lodz, Poland, 2007.

[23] http://www.infineon.com/cms/en/product.

***Authors**: prof. dr hab. inż. Janusz Zarębski, e-mail: zarebski@am.gdynia.pl; dr inż. Jacek Dąbrowski, e-mail: oakjack@am.gdynia.pl; Gdynia Maritime University, Department of Marine Electronics, 81-225 Gdynia, ul. Morska 83.*