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A method of the thermal resistance measurements of semiconductor devices with p–n junction

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Abstract

In this paper the problem of measuring the thermal resistance of silicon semiconductor devices including p–n junction – available for a user, is considered. The values of the thermal resistance given in the catalogues rarely correspond to the real conditions of device cooling. Therefore, the value of the thermal resistance has to be obtained from measurements. In the paper a new convenient method of the measurements of the thermal resistance of silicon semiconductor devices with p–n junctions, based on the measurements of d.c. current–voltage characteristic of the junction and the estimation of the model parameter values with the use of SPICE MODEL EDITOR – software, is presented. The results of the measurements obtained with the new method are compared to the standard pulse method. The proposed method can be applied for such devices as: p–n diodes, power MOS transistors, Darlington transistors as well as IGBTs having the antiparallel diodes.

Keywords: Thermal resistance; Semiconductor devices; Thermal parameters; Measuring method

1. Introduction

A very important problem of semiconductor devices measurements is to estimate a device inner temperature, influencing their $i(v)$ characteristics and their reliability. The value of the device inner temperature can be estimated with the use of the thermal resistance (R_{th}) of the investigated device. The values of R_{th} given in the catalogue data concern either the ideal conditions of the heat removal from the device or the conditions of device cooling are not defined. On the other hand, as it results from literature [1–3] and the authors' experience [4], the device thermal resistance value can change even in the wide range depending on both: the device operating point coordinates (e.g. the current or power value) and the used method of the measurement of the considered device.

Generally, to measure the device thermal resistance the optical, chemical and electrical methods can be used. It is important to notice, that only electrical methods are non-destructive ones. In these methods the dependence of a selected electrical parameter (most often the voltage on the forward-

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biased diode) on temperature (called a thermosensitive parameter) is used. Such a dependence is called the device thermosensitive characteristic (DTC). The thermal resistance is obtained from

$$R_{th} = \frac{T_j - T_a}{P} \quad (1)$$

where P is the power dissipated into the investigated device, T_a is the ambient temperature, T_j is the junction (inner) temperature calculated on the basis of DTC.

The existing electrical methods of the measurements of the thermal resistance of silicon p–n diodes have some disadvantages. For example, these methods demand two ambient temperatures [5], a special measuring set using the pulse method [1], or they can be realised only at the breakdown range [5].

In this paper, which is the extended version of [6], a new measuring method of the thermal resistance of semiconductor devices including p–n junction is presented. This method is based on the measurement of the non-isothermal $i(v)$ d.c. characteristic of this junction and the use of SPICE MODEL EDITOR software for the estimation of the diode parameter values. The device thermal resistance value is calculated by the simple equation proposed by the authors.

The main advantage of the method is its easy realisation with the use of simple measuring instruments, which are available in each laboratory. This method has been used to measure the thermal resistance of two diodes – the Zener diode BZX85C24 and the power rectifier diode D01-10-10, as well as the Darlington transistor BU323A having the antiparallel diode situated between the emitter and the collector terminals.

2. Description of the method

In the proposed method, to obtain the thermal resistance of the investigated device, the voltage–current characteristic of the device available p–n junction is taken into account [7]

$$v = f(i, T_j, \underline{\text{par}}) = N \cdot h \cdot T_j \cdot \ln\left[\frac{i \cdot \left(i + \sqrt{i^2 + 4 \cdot \text{IKF}^2}\right)}{2 \cdot \text{IKF} \cdot \text{IS}}\right] + \text{RS} \cdot i \quad (2)$$

where i, v denote the current and voltage on the junction, h is the quotient of the Boltzmann constant and the electron charge, whereas $\underline{\text{par}} = [\text{IS}, \text{N}, \text{RS}, \text{IKF}]$ is the vector of the model parameters.

The values of the saturation current (IS) and the junction series resistance (RS) depend on temperature. The following temperature dependence of these parameters has been taken into account [6]

$$\text{IS} = I_0 \cdot \left(\frac{T_j}{T_0}\right)^{1.5} \cdot \exp\left(-\frac{U_{go}}{h \cdot T_j}\right) \quad (3)$$

$$\text{RS} = \text{RS}_0 \cdot (1 + \alpha_{RS} \cdot (T_j - T_0)) \quad (4)$$

where $U_{go} = 1.206$ V for silicon, I_0 is the parameter independent of temperature, T_0 denotes the reference temperature, RS_0 denotes the value of the series resistance in the temperature T_0, whereas α_{RS} is the temperature coefficient of this resistance.

In the further part of this chapter the estimation of the junction parameter values by means of SPICE MODEL EDITOR – software is described and the algorithm of the new method is presented.

2.1. The junction model parameters estimation

In the equations describing the junction characteristic (Eqs. (2)–(4)), two groups of parameters can be distinguished. The first (parameters: IS_0, N_0, RS_0, IKF_0) describe the isothermal voltage–current characteristics of the junction at the fixed room temperature T_0 equal to 300 K. The values of these parameters can be determined by means of SPICE MODEL EDITOR (for a diode model). For this purpose the coordinates of some measured points lying on the considered characteristic obtained at 300 K have to be introduced to SPICE MODEL EDITOR as its input data. To obtain all parameter values, at least four test points should be taken into account, but the best solution can be expected when a dozen or so points distributed uniformly on the characteristic are taken into account.

As the isothermal characteristic of the junction is necessary, the electrical power at the test points should be negligible so that the investigated device inner temperature and the ambient one can be of nearly the same values. On the other hand, the junction current has to be of a sufficiently high value so that the generation-recombination current component (not included in Eq. (2)) can be neglected.

By means of SPICE MODEL EDITOR, the following values of parameters have been obtained: for BZX85C24: $\text{IS}_0 = 7.16$ fA, $N_0 = 1.0478$, $\text{RS}_0 = 0.335\ \Omega$, $\text{IKF}_0 = 1$ kA, for D-01-10-10: $\text{IS}_0 = 19.1$ nA, $N_0 = 1.722$, $\text{RS}_0 = 0.018\ \Omega$, $\text{IKF}_0 = 1$ kA