Microelectronics Reliability xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Microelectronics Reliability

journal homepage: www.elsevier.com/locate/microrel

# Experimental investigation of discrete air cooled device thermal resistance dependence on cooling conditions

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ARTICLE INFO

*Article history:*
Received 20 February 2017
Received in revised form 5 May 2017
Accepted 6 May 2017
Available online xxxx

ABSTRACT

Temperature is an important factor influencing the operation of electronic devices, thus adequate thermal models should be used for their accurate simulations. Unfortunately, the information on device thermal characteristics provided by their manufacturers is very scarce and usually it is limited only to the specification of the junction-to-case thermal resistance, which is not sufficient for the prediction of device dynamic thermal behaviour.

This problem is discussed here based on the practical example of an air cooled power device operating at different power dissipation levels and in variable cooling conditions. The experiments presented in this paper demonstrate that the notion of junction-to-case thermal resistance is ambiguous since the cooling conditions affect the heat diffusion processes inside the package and consequently influence the thermal resistance value. For the analysed device, a simple four-stage RC Foster ladder model is proposed here to simulate the device dynamic thermal behaviour. Owing to the fact that this model is generated in a structure preserving way, its element values can be assigned some physical meaning.



## 1. Introduction

The continuous miniaturization of state-of-the-art electronic devices and the increase of their operating frequency lead to the significant growth of dissipated power density. Consequently, thermal modelling and management of electronic systems are nowadays one of the most important research areas since a vast majority of system malfunctions or failures are due to thermal reasons [1].

Theoretically, in order to obtain accurate temperature simulation results, detailed thermal models of electronic systems should be used. Unfortunately, the solution of such models frequently is a time demanding task due to the complexity of problem geometry. Moreover, manufacturers very unwillingly reveal any information on the internal device structure and thermal data provided by them are very scarce.

Usually, as it is in the case of a power device analysed here, the dynamics of thermal processes is completely ignored in datasheets and the information is limited only to the specification of junction-to-case thermal resistance in some unknown boundary conditions, hence it does not meet at all the requirements specified in the guidelines specified in the JEDEC standard [2].

Obviously, there exist solutions created within the EU funded projects DELPHI and PROFIT focused on the development of a methodology to generate boundary condition independent compact thermal models [3]. Such models have been standardised and they are widely used in industry [4].

The main drawback of the DELPHI style compact models is that they require a huge computational effort to generate and validate them. Besides, despite the fact that they produce accurate simulation results, the entire information on the internal package structure is absent in the model. In this paper we discuss these issues based on the example of an air cooled power device where its dynamic thermal behaviour in various cooling conditions is analysed.

The following section of this paper presents in detail the results of power device dynamic temperature response measurements carried out at different power dissipation levels and in variable cooling conditions. Next, the results are analysed employing the Network Identification by Deconvolution (NID) method [5]. Then, the identified partial thermal resistances and capacitances in the heat flow path are used to generate compact thermal models. Finally, the simulated device heating curves are compared with the measured ones.

## 2. Temperature measurements

The experimental results presented in this paper concern a commercially available silicon carbide diode mounted in the standard TO-220 package rated for the forward current of 5 A and the reverse blocking voltage of 1200 V. During measurements the device was first heated

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http://dx.doi.org/10.1016/j.microrel.2017.05.008

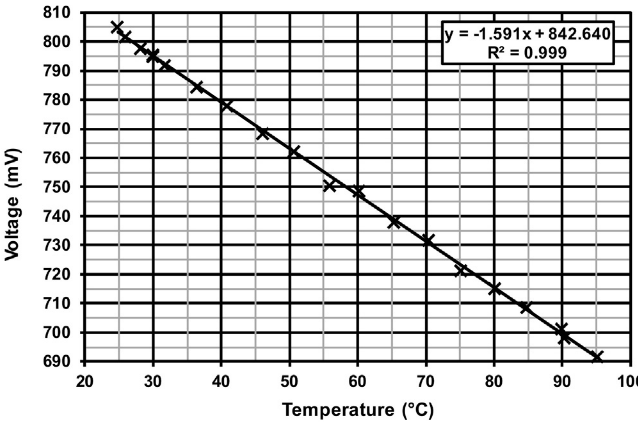


**Fig. 1.** Diode calibration curve measured at 10 mA forward current.

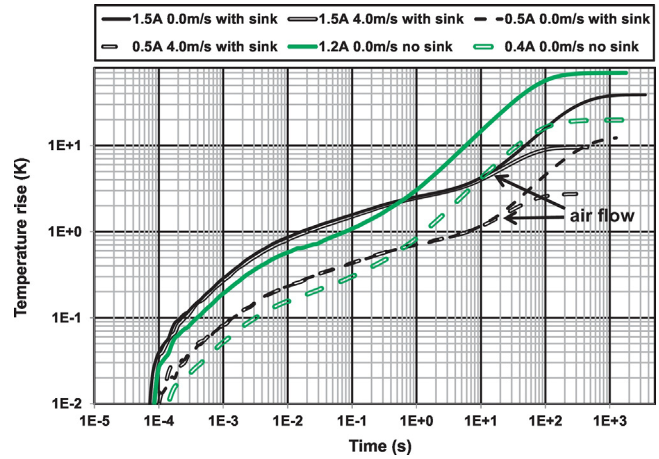


**Fig. 3.** Measured diode heating curves.

with a constant forward current value until thermal steady state conditions were reached. Then, the power was switched off and the cooling curve was recorded forcing the forward current of 10 mA. During the measurements the voltage drop across the junction was registered with the transient thermal tester T3Ster manufactured by Mentor Graphics.

Before the actual measurements, the device was calibrated on a cold plate for the above-mentioned measurement current value. The measured dependence of the voltage drop across the diode junction is shown in Fig. 1. As can be seen, the voltage decreases linearly with temperature at the rate of 1.59 mV/K. This value was used then in all the measurements presented throughout this paper.

First, the cooling curves were recorded for the diode without any heat sink. Then, the device was firmly screwed to an aluminium heat sink whose parameters, such as surface area and volume, were provided by its manufacturer, what was very useful for thermal analysis purposes. The cross-sectional view of the heat sink together with its dimensions and other data are shown in Fig. 2. Additionally, the diode location is also indicated in the figure.

Initially successive measurements were carried out for the device without the heat sink in still air conditions and the heating current was stepped up from 0.1 A to 1.5 A with the step of 0.1 A. When the heat sink was attached, the upper limit was increased to 2.0 A. Then, the diode with the heat sink was placed horizontally with thermally insulating clamps in a wind tunnel where the air velocity is known to be laminar. The wind tunnel was built in accordance with the JEDEC standard for environmental conditions with forced air convection cooling [6]. The measurements in the tunnel were carried out with the air velocity ranging from 0.3 m/s to 4.0 m/s and the diode heating currents of 0.5 A, 1.0 A, 1.5 A and 2.0 A.

Selected measurement results, which will be analysed in detail later on in this paper, are shown in Fig. 3. For a more complete presentation of measurement results, refer to [7]. The curves are plotted in the figure on the double logarithmic scales as heating curves, which were obtained by subtracting the measured values from the respective diode temperature steady state rise values. The results for the device without the heat sink are represented with the lighter lines, the curves obtained with forced cooling are plotted with the double lines whereas the ones for lower current values with the dashed ones.

Initially all the curves have similar shape and then they diverge in locations depending on the imposed cooling conditions. The curve separation points in the case of forced convection measurements, indicated by the arrows, are located around the time value of 16 s when the cooling conditions at the heat sink surface start to affect the curves. The precise determination of the separation points in the case of the device without the heat sink is more difficult. For that purpose, the heating curves in still air without the heat sink were multiplied by the factor equal to the ratio of dissipated power values so that the curves for the heating currents of 0.4 A and 1.2 A initially coincide with the respective curves for the currents of 0.5 A and 1.5 A. Accordingly, the power ratio values used for the multiplication were equal to 1.537 and 1.504.

The curves obtained in the above described way are presented in Fig. 4 which shows a magnified view of the curves near their separation points. As can be seen, both lighter curves diverge form the black ones in the locations marked in the figure by two dashed arrows already before 100 ms. This indicates that without the heat sink the cooling conditions affect the curves much earlier because of smaller thermal capacity of the entire structure and, the most probably, because of the altered heat flow path inside the package.

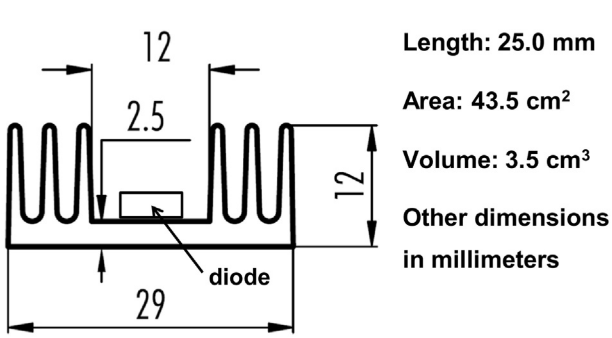


**Fig. 2.** Heat sink data.

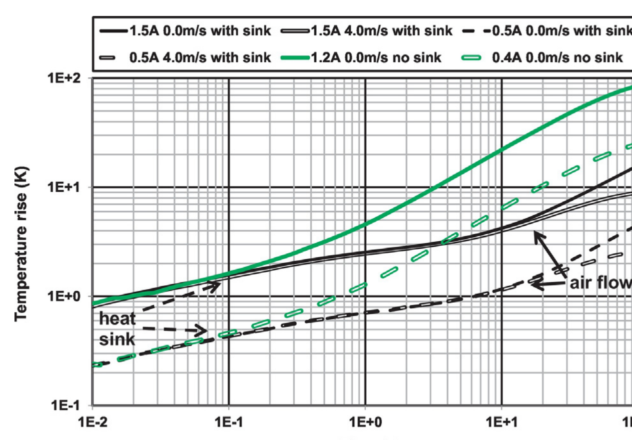


**Fig. 4.** Magnified view of heating curves with normalised curves for the device without the heat sink.

Please cite this article as: M. Janicki, et al., Experimental investigation of discrete air cooled device thermal resistance dependence on cooling conditions, Microelectronics Reliability (2017), http://dx.doi.org/10.1016/j.microrel.2017.05.008