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Thermographic temperature measurements of the semiconductor devices made on the basis of SiC

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Abstract

This article presents a thermal test of the FFSH10120A diode. The use of thermography in monitoring its temperature is described in detail. The use of the FFSH10120A diode, which is a high-power semiconductor component, is associated with thermal problems. The influence of the power supplied to the diode and the ambient conditions on its temperature were analyzed. The use of thermography enabled the precise and non-invasive monitoring of this temperature, which allows identifying the areas with excessive temperature and taking appropriate countermeasures. The conducted research provide valuable information regarding the optimal operation of the FFSH10120A diode to ensure its durability and efficiency.

1. Introduction

The excessive temperature rise of working semiconductor components is one of the main challenges faced by electronics engineers and designers. The effects of overheating can be catastrophic, leading to damage of the semiconductor components, shortening their life and improper operation of the devices in which they are placed. Therefore, monitoring the temperature of semiconductor components is critical to ensure optimal performance and durability of these devices. In this context, thermography becomes a valuable tool that enables the non-contact and precise monitoring of the temperature of semiconductor components, including the FFSH10120A diode.

The FFSH10120A diode is a semiconductor device that is made on the basis of SiC silicon carbide. It is characterized by a high value of power that can be dissipated in it [1]. It is widely used in the various applications, such as power systems [2], energy converters [3] or lighting systems [4]. During operation, this diode generates a significant amount of heat that must be properly dissipated to prevent overheating. Contact methods of the temperature measurement involving placing the sensor to the case have the disadvantages and are impractical. When the diode is placed in an electronic device, the points where the measurement can be made are difficult to reach. The thermal resistance between the sensor and the diode case is also unknown. In addition, there is a risk of electric shock. An alternative way to measure this temperature is thermography, which enables the non-contact and comprehensive monitoring of the temperature of the FFSH10120A diode.

The advantages of thermographic temperature measurement are numerous and valuable for the thermal analysis of the FFSH10120A diode. The first is the quick detection of the areas with the elevated temperature. This enables early response and appropriate countermeasures, such as improving the cooling system or modifying the design of the device containing the diode. The second advantage is the identification of temperature unevenness on the surface of the diode case, which may indicate problems with heat dissipation or improper assembly to the cooling system. This information is extremely valuable in optimizing the design and improving the thermal efficiency of the diode. The third advantage is the ability to perform thermal analysis during load tests, allowing the FFSH10120A diode to be evaluated under various operating conditions and loads.

In the case of the FFSH10120A diode, most of the generated heat is concentrated inside the case. However, infrared radiation in the spectral range that corresponds to the range of the camera used does not penetrate the case of the semiconductor device. This makes it impossible to perform a direct thermographic temperature measurement of the semiconductor element located inside the case. For this reason, it was decided to undertake research work aimed at developing a method of indirect thermographic temperature measurement of a semiconductor element made on the basis of SiC.

2. Methodology

In the conducted research, as a representative example of a semiconductor device made on the basis of SiC, the FFSH10120A diode (Onsemi, Pxoenix, AZ, USA) was used, which was placed on the RAD-DY-KY/3 heat sink. The work consisted of three stages: thermographic temperature measurement of the semiconductor device, thermographic temperature measurement of the case of the semiconductor device, and the determination of the relationship between the temperature of the semiconductor device and the temperature of the case of the semiconductor device. The thermographic temperature measurement of the semiconductor element was made after opening the case.

Optris Xi 400 thermographic camera equipped with a suitable matrix and a microscope lens was used. The lens of the camera used has a shallow depth of field. It was necessary to precisely adjust the distance *d* between the camera's optics and the case of the semiconductor device. This was achieved by placing the camera on a tripod that allowed the distance *d* to be set. In order to limit the influence of reflected radiation on the result of thermographic temperature measurement, the camera and tripod were placed in a chamber made of plexiglass, lined with polyurethane foam, which was characterized by a high value of the emissivity coefficient equal to 0.95. In order to eliminate the problem of not knowing the value of the emissivity coefficient of the surfaces which temperature was measured, the measurements were made on markers painted with Velvet Coating 811-21 paint.

The difference between the temperature of the semiconductor element and the temperature of the case of the semiconductor device was determined on the basis of simulation work consisting in determining the temperature distribution in the case of the FFSH10120A diode. FEM (Finite Element Method) and Solidworks 2020 SP05 software (Dassault Systèmes, Vélizy-Villacoublay, France) were used. The use of this software was possible after making three-dimensional models showing the analyzed diode and heat sink. In turn, making models was possible after previous knowing the dimensions of the analyzed semiconductor device and heat sink. It was also necessary to know the materials from which they were made and the properties of these materials. A photo of the tested diode with an example thermogram is shown in Fig. 1.

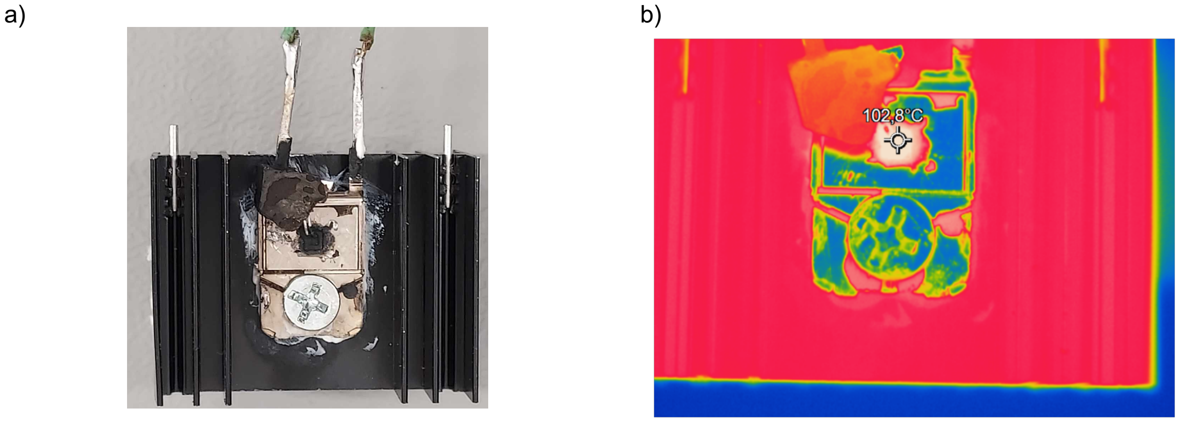

Fig. 1. a) The tested FFSH10120A diode with heat sink, b) An example of a thermogram recorded at the power dissipated in the junction *P* = 10.9 W.

The conducted research was aimed at improving the method of indirect thermographic temperature measurement of a semiconductor element. In order to determine the temperature distribution, it was necessary to determine the emissivity of the case and the convection and radiation coefficients. In order to determine the emissivity coefficient, instead of an element with an open case, an element with a closed case was placed. In the first step, the case temperature was measured using thermography on a marker painted with Velvet Coating 811-21 paint. Then the measuring point was placed on the part of the case that was not painted. The care was taken to ensure that both locations of the measurement points were as close as possible. In the next step, the emissivity setting in the camera was changed until the temperature readings at both points were equal. The emissivity value for which the readings were equal was the selected emissivity value.

The value of the radiation coefficient h_r was obtained using equation 1 [5]

$$h_r = \varepsilon \cdot \sigma_c (T_c + T_a)(T_c^2 + T_a^2) \tag{1}$$

where σ_c is Stefan–Boltzmann constant equal to 5.67×10^{-8} ($\mathrm{W \cdot m^{-2} \cdot K^{-4}}$), T_a is the ambient temperature (K) and T_c is the case temperature (K).

To determine the value of the convection coefficient h_c, equation 2 was used [6]

$$h_c = \frac{Nu \cdot k}{L} \tag{2}$$

where: Nu is the Nusselt number (-), and L is the characteristic length in meters (for a vertical wall, it is its height). Analyzing the equation (2), it was noticed that it is necessary to determine the Nusselt number (Nu). This was implemented using the equation 3 [7]

$$Nu = a(Pr \cdot Gr)^b \tag{3}$$

where: a and b are dimensionless coefficients, the values of which depend on the shape and orientation of the analyzed surface and the product Pr × Gr, and Gr is the Grashof number.

The equation 3 contains the coefficients a and b, the value of which depends, among others, on the shape of the analyzed wall of the semiconductor element, its position (vertical, horizontal) and the air flow around this wall. The values of these coefficients for the selected wall are presented in the Table 1.

Table 1. The values of coefficients a and b [7].

Shape	***Gr· Pr***	a_{lam}	b_{lam}	a_{turb}	b_{turb}
Vertical flat wall	10^9	10^9	0.59	0.25	0.129
Upper flat wall	10^8	10^8	0.54	0.25	0.14
Lower flat wall	10^5	10^5	0.25	0.25	NA

The Prandtl number was obtained based on the equation 4 [8]

$$P_r = \frac{c \cdot \eta}{k} \tag{4}$$

where: *c* is the specific heat of air equal to 1005 $(\mathrm{J \cdot kg^{-1} \cdot K^{-1}})$ in 293.15 (K), *η* is dynamic air viscosity equal to 1.75×10^{-5} $(\mathrm{kg \cdot m^{-1} \cdot s^{-1}})$ in 273.15 (K).
The last missing Grashoff number was determined based on the equation 5 [9]

$$Gr = \frac{\alpha \cdot g \cdot (T_S - T_a) \cdot \rho^2 \cdot L^3}{\eta^2} \tag{5}$$

where: *ρ* is the air density equal to 1.21 (kg·m−3) in 273.15 (K), L – the characteristic length (m) – in the case of vertical elements it is the height, *g* – the gravitational acceleration equal to 9.8 (m·s−2), α – the expansion coefficient equal to 0.0034 (K−1), - T_s – the Surface temperature, T_a – the ambient temperature.

3. Results

The conducted research was aimed at improving the method of indirect thermographic temperature measurement of a semiconductor element. By analyzing the relationship between the temperature of the case of the semiconductor device and the temperature of the semiconductor component and the power dissipated in the junction, a new approach to temperature monitoring was developed. The greater precision and accuracy have been achieved in monitoring and controlling the temperature of the semiconductor component, which could help improve the performance and reliability of these components. The largest difference between the temperature of the semiconductor element and the temperature of the case of the semiconductor device determined during the tests was 73.6 ℃, while the difference between the temperature of the semiconductor element and the temperature of the heat sink was 54.2 ℃.

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