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Power cycling analysis method for high-voltage SiC diodes

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ABSTRACT

This work describes a novel analysis method for the power cycling test, developed for high-voltage and temperature silicon carbide diodes. The silicon carbide devices working at temperatures beyond 170 °C, the maximum temperature rating for silicon devices, need specific reliability tests adapted to high temperature operation of this new generation of power devices. The specificity of the further presented method consist in the use of 10 ms sinusoidal power current pulses that are able to evidence the temperature developed inside the diode during the power pulse, the temperature characteristic delay versus the applied current and the temperature calibration method. Moreover, this overall method is able to evidence the transformations occurred in the bonding contact and the dye attach.

1. Introduction

The increasing demands for high efficient energy conversion in modern systems open new opportunities for the wide band gap power devices market growth. The new generation of **s**ilicon **c**arbide (SiC) power devices is able to ensure increased performance of power systems [1]. The voltage rating of commercially available silicon carbide diodes is actually limited to 1.2 kV. The new challenge is the mass production of high-voltage SiC power devices from 1.7 kV up to 10 kV. There are EU-funded initiatives to increase the voltage rating of SiC devices. The European Project SPEED [2,3] supports a group of companies and research institutions to focus on new SiC power devices for novel specific applications, such as wind power and solid state transformers (SST) for smart electric grids.

The improved capability of SiC devices to operate at high temperature and/or high current density brings a new challenge in terms of packaging reliability.

This study performed into the framework of the “SPEED” European Project is dedicated to the power cycling robustness of 3 to 5 kV JBS diodes. However, the following presented method can be applied to a large class of power devices.

The method is able to evidence not only the lifetime robustness of the diode to power cycling but also the instantaneous temperature of the device during the power current pulse and degradations occurred in the die-attach and the bonded wires. The following sections will present in detail the example of the novel power cycling analysis method.

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2. Description of the power cycling analysis method

The novel proposed method is based on previous power cycling test method [4] that compares the evolution of the dissipated energy during the power cycling at 10 ms/1 Hz half sine pulse. After assuming a starting dissipated energy, the correspondent current amplitude is maintained constant. The degradation is evidenced by the dissipated energy change that is an overall signature of the diode's degradation by runaway mechanism. It is important to compare the same class of diodes submitted to the same starting energy.

In the novel method presented in this paper, new setup criterion and result analysis are introduced. The starting energy and its associated test current are established knowing the temperature sweep of the diode during the current pulse. According to this method, the temperature sweep of the diode is the key starting point. Having in mind that the temperature sweep is due to the self-heating, we have elaborated an indirect evaluation method of temperature sweep using the hysteresis *I–V* curve. The peak current value is selected to produce a relevant temperature sweep induced by self-heating (Fig. 2). The test pulse energy is calculated from the integral of power pulse shown in Fig. 1.

The mathematical expression of pulse dissipated energy E_{d0} as integral of the instantaneous product of current to voltage during the pulse period is shown in (Eq. (1)):

$$E_{d0} = \int_0^{10\ \mathrm{ms}} p_d(t)dt = \int_0^{10\ \mathrm{ms}} i_d(t)v_d(t)dt \tag{1}$$

where t is the time, and $p_d(t)$, $i_d(t)$, and $v_d(t)$ are the diode's instantaneous power, current and voltage, respectively.

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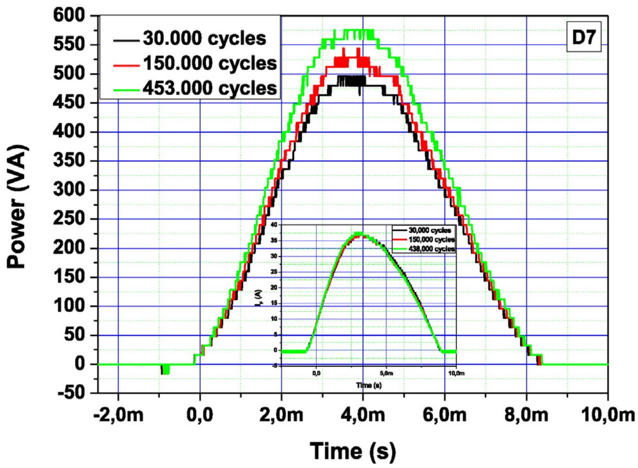

Fig. 1. Instantaneous dissipated power inside the diode after various applied test pulses.

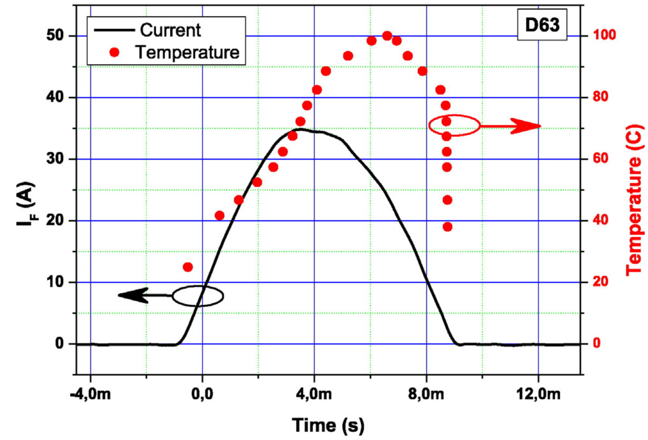

Fig. 3. Delay of the temperature versus the applied current pulse.

As an indication, the peak current has a rough value of 70% of the destruction peak surge current and is not recommended to be exceeded.

To comparing different samples, the same starting energy value should be used for all the samples.

For temperature evaluation during the pulse current, a prior isothermal calibration at different temperatures was done. The isothermal plots are performed at various device temperatures using very short current pulses in order to avoid supplementary temperature increase of the measured diode. The temperature calibration principle is illustrated in Fig. 2. The isothermal *I*–*V* curves are superposed over the hysteresis *I*–*V* graph recorded during the high current pulse. The intersections between the hysteresis curve and the various isothermal plots give information on the temperature reached during the high current pulse (see Fig. 2).

The plot of temperature versus time during the current pulse for the D63 sample is shown in Fig. 3. The temperature versus time graph is obtained from a graph similar to Fig. 2 combined with the graphs (or the recorded tables) of current versus time and voltage versus time. The negative time in the graph is related to zero point reference of the oscilloscope. Due to the hysteresis, two voltage and temperature values are associated to the same current value, so we can trace the ascending and descending values of the temperature. One can observe in Fig. 3 that diode's current and temperature are not in phase, and the maximum temperature is not reached at the maximum current peak. A time delay of ~2.5 ms between the maximum current value and the maximum temperature value is obvious. This delay is due to the thermal impedance of the packaged diode. Since the maximum temperature is not reached at the maximum current, the voltage drop measurement on the top current time during power cycling is not relevant. Thus, the option for the 10 ms sinusoidal sweep current instead of rectangular pulses is justified. Using rectangular pulses, much useful information would be lost. The measuring of pulse energy evolution is able to evidence both the self-heating temperature effects and the transformation of bonding and die attach during power cycling. Significant changes in die attach influence the thermal resistance and consequently the maximum reached temperature.

3. Experimental results and discussions

3.1. Power cycling robustness

Two similar diodes D7 and D63 having different layout bonding were submitted to a lifetime test. The graph of Fig. 4 shows the evolution of dissipated energy as function of number of power cycles up to the collapse of the tested diodes. D63 has the bonding contacts in line near one border of the chip metallization. The bonding wires of D7 are placed uniformly over the chip's surface. Both diodes started the test from the same energy $E_{d0} = 2.3$ J, at constant current amplitude of 35.2 A and 37.6 A for D63 and D7, respectively. However, even the both diodes were submitted to the same test conditions, the diode D63 having wire bonding placed lateral collapsed prematurely after

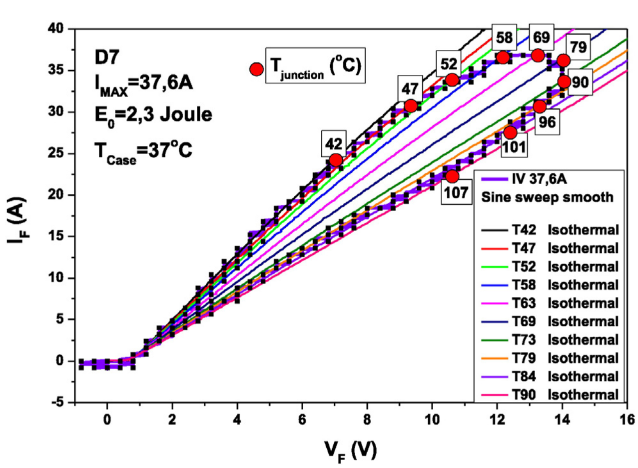

Fig. 2. Example of temperature evaluation method on the hysteresis *I*–*V* curve.

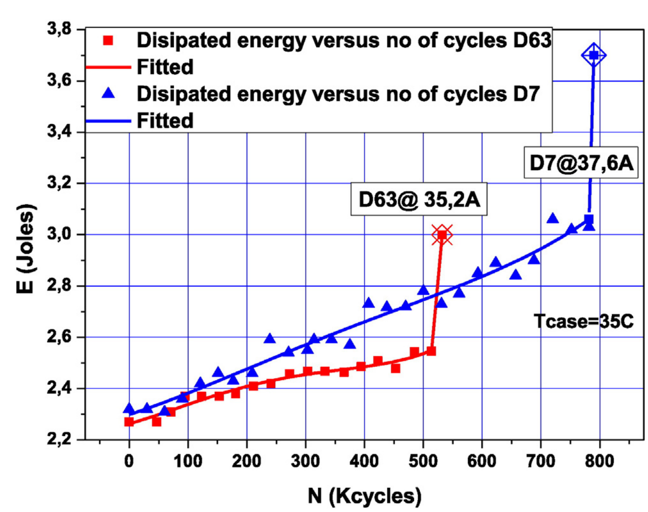

Fig. 4. Lifetime test. Evolution of dissipated energy versus the applied number of power cycling pulses.