Engineering Failure Analysis 83 (2018) 185–192

Contents lists available at ScienceDirect

Engineering Failure Analysis

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

Failure investigation of packaged SiC-diodes after thermal storage in extreme operating condition

Olivier Latry[a], Pascal Dherbecourt[a,*], Patrick Denis[a], Fabien Cuvilly[a], Moncef Kadi[b]

[a] University of Rouen-Normandie, GPM UMR CNRS 6634, Avenue de l'université, BP12, Saint Etienne du Rouvray 76801, France
[b] IRSEEM, EA 4353 at Graduate School of Engineering ESIGELEC, Avenue Galilée, BP 10024, Saint Etienne du Rouvray 76801, France

ARTICLE INFO

Keywords:
Electronic-device failures
Failure analysis
Microanalysis
Reliability analysis
Thermal stress

ABSTRACT

Ageing tests through thermal storage at high temperature (240 °C) are carried out on commercial Schottky diodes in TO220 package, in “derating mode” operational conditions. The analysis revealed a failure mechanism, resulting into vaporization of the moisture present in significant quantity in the resin/sole interface. As a consequence, a degradation of the resin, freeing up space, caused the solder to spread under the chip. The X-ray analyses, acoustic microscopy SAM, optical and electron microscopy are used to describe the failure mechanism. We note that the resin package has undergone a strong degradation. Investigations show that this phenomenon is fully responsible for the degradation process taking place in derating mode use.

Most components behave similarly with respect to the ageing; however, an atypical and unusual result is revealed for one component after the ageing process. Thus, the specific case is presented as a potentially decisive case for the validation of a failure analysis, so that technical solution can be formed.

1. Introduction

Temperature is one of the major concerns of reliability of power semiconductors as it may induce ageing or catastrophic failures such as short or open circuits within electronic devices. In light of the new constraints in mechatronic applications of the latest generation, the development of silicon carbide SiC for power electronics is booming. Silicon carbide diodes and transistors have been commercially available since 2001 and 2008 for standard applications, such as power factor corrector, limiter, and more recently, for systems of energy conversion. Several generations of these components have emerged and offer increasing improved performance, particularly in terms of efficiency. SiC technology has many advantages over conventional silicon technology, and enables electronic devices to be used at higher temperature (600 °C) [1] without reducing performance.

SiC Schottky diodes are expected to work at high voltage and at high temperatures during operation mode, exploiting the advantage of silicon carbide over silicon, when submitted to very high thermal environment. Some studies reported reliable chemical and physical stability of SiC Schottky component. Macroscopic parameters, ideality factor and barrier height, do not change under temperature close to 400 °C [2]. Silicon carbide chips are extremely reliable and robust against temperature, but material composition and packaging have limitations at high temperature conditions.

Electronic components are usually packaged in plastic encapsulation. The main advantage of using plastic encapsulation is to reduce costs, especially for large production volumes. In the early 1970s, plastic encapsulation processes became reliable enough to meet the needs of industrial equipment, as plastic packaging has steadily pushed its intrinsic limitations.

* Corresponding author.
E-mail address: pascal.dherbecourt@univ-rouen.fr (P. Dherbecourt).

http://dx.doi.org/10.1016/j.engfailanal.2017.09.010
Received 25 April 2016; Received in revised form 5 September 2017; Accepted 28 September 2017
Available online 29 September 2017
1350-6307/

However, the first limitation attributed to plastic package is their permeability to water, even leaks between the resin structure and the metallic conductors, while hermetic packaging completely isolates the semiconductor from the outside environment. The second limitation is the limited thermal dissipation compared to similar ceramic packages. Heat dissipation is restricted by the limited thermal conductivity of plastic materials. This feature is essential for power components and can require the particular conditions of an extra cooling equipment to meet the environmental constraints of the targeted application.

Another limitation is mechanical fatigue, since the molding resin includes interconnection bonding and is in contact with the semiconductor. Significant and repeated temperature changes can damage the bonding or the metallization of the semiconductor, or degrade the adhesion of the resin to the leadframe [3].

SiC diodes with resin epoxy package are generally qualified for temperatures of 175 °C, whereas the maximum temperature is 150 °C for silicon technology. In critical context, the equipment designers do not have components that meet functional environmental temperature conditions, so they choose to use components in “uprating” or “derating” mode rather than invest in dedicated and expensive high temperature packaged devices [4].

A rating is a value which establishes either a limiting capability or a limiting condition for an electronic device. It is determined for specific values of environment and operation. Limiting conditions may be either maxima or minima. Recommended operating conditions are the ratings for which the electrical specifications are guaranteed.

“Uprating” is a term used in the industry to describe the use of components outside manufacturers' specification. The “uprating” mode consists in using a component at temperatures for which it is not qualified, and in establishing another estimation of time to first failure (MTTF). The risks can be segregated into three categories. Firstly, the reliability of the die: The capability of the die to operate in the desired environment without physical degradation. Secondly, the package reliability: The capability of the packaged component to withstand exposure to the desired environment without failing. Thirdly, electrical performance: The capability of the component to perform its electronic function in the desired environment [5].

Derating consists in limiting thermal, electrical and mechanical stresses on an electronic part to levels below the manufacturers' specifications to improve the reliability of the part [6]. The derating mode often requires reduce nominal operating conditions, to reduce self-heating and re-balance the junction temperature caused by an increase in environmental temperature.

Considering both uprating and derating modes, generated failure mechanisms are poorly understood. The precise knowledge of the mechanism and of the cause of failure could help designers.

The objective is to evaluate the derated characteristics of the potential candidates for extreme temperature application due to the unavailability of high temperature packages. Moreover, new failure mechanisms may be encountered, which represents another important issue of this task. Distinguishing the failure mechanism due to temperature overstress could help find a solution to improve this reliability issue.

The work presented in this paper offers a detailed description of the failure mechanism, simultaneously for the case observed for a majority of the components, and also for a particular case presenting low degradation. The reliability of a commercial plastic package device beyond its maximum operating temperature is investigated to understand the mechanisms of failure. Several studies [7,8] have been conducted on the effect of high temperature devices focusing on the bare die or rather directed to the bonding, solder joint or package degradations for this kind of stress and application. Microstructural investigation has been developed in this paper to have a comprehensive view of devices and to describe an overall approach of failure analysis methodology in derating mode use.

2. SiC Schottky diodes description and ageing conditions

2.1. SiC diode component description

Components under study are silicon carbide Schottky diodes with TO-220 packages in epoxy resin. The component data sheet indicates a maximum junction temperature of 175 °C. These devices are designed to withstand a 1200 V breakdown voltage and to support a 5 A DC current in forward mode. The design is illustrated in Fig. 1, and defined in the following nomenclature.

The manufacturer describes the materials composing the packaging in a “material declaration report”. EDX analyses confirm the nature of some elements and complete our data by revealing the chemical elements distribution of the solder joint. The global composition of the elements of the packaging is summed up below:

- The die is made of 100% silicon carbide;
- The bonding of 100% aluminium;

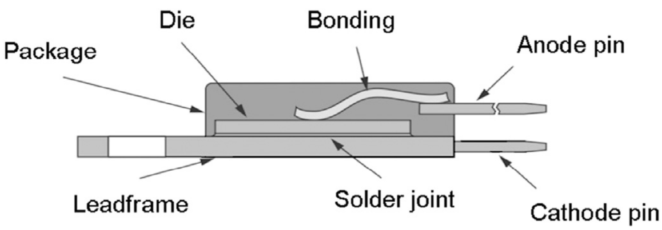

Fig. 1. Schematic view showing the die, the package and the connecting elements of the device.