Thermal Characterisation as a Part of Reliability Testing of THz Schottky Diodes

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Abstract

This paper presents the most common thermal characterisation methods for semiconductor diodes and discusses why thermal characterisation is important for the diode reliability assessment. A special case of thermal characterisation of THz frequency Schottky diodes for MetOp Second Generation (MetOp-SG) satellite program instruments is covered in more detail. The benefits of accurate thermal characterisation in this case are explained and the drawbacks of unknown self-heating are discussed.

1 Introduction

Thermal characterisation, or measuring the temperature response of a circuit or a component to the internal self-heating, is one of the key tasks in the evaluation of semiconductor devices, such as diodes and transistors [1]. The reason for the increased importance of the thermal characterisation is the continuing trend of semiconductor devices toward smaller, faster and more powerful applications. Smaller and more powerful are contradictory requirements in the thermal world. Together, they mean increased heat flux densities and therefore increased junction and die temperatures, leading to accelerated aging and thermally induced failures.

2 Thermal characterisation methods

A typical goal in thermal characterisation is to find out the total thermal resistance of the circuit. This enables the estimation of the junction temperature when power consumption is known. More generally, a circuit usually has several thermal resistances (or impedances) and thermal time constants. The junction temperature can be expresses as

$$T_J = T_0 + PR_\theta \,, \tag{1}$$

where T_0 is the ambient temperature, P is the power consumed in the junction and R_θ is the total thermal resistance, or often called only the thermal resistance.

Main idea in most thermal characterisation methods is to find out the junction temperature, and, with this knowledge and the knowledge of the power consumption, calculate the thermal resistance. Limiting the applications in semiconductor testing, the most typical methods are direct thermocouple measurement, infrared imaging, utilization of a reference device, and electrical test method [1], [2]. When considering only extremely small monolithically integrated devices (MMICs), the applicable methods are infrared imaging and electrical test method.

Determining the junction temperature with infrared imaging is straightforward. One needs only an infrared microscope. However, this approach has three unfortunate drawbacks. First, the pixel size in state-of-the-art infrared microscopes is in the order of 10 µm^2, which is too much for the accurate characterisation of the extremely small junctions of state-of-the-art Schottky

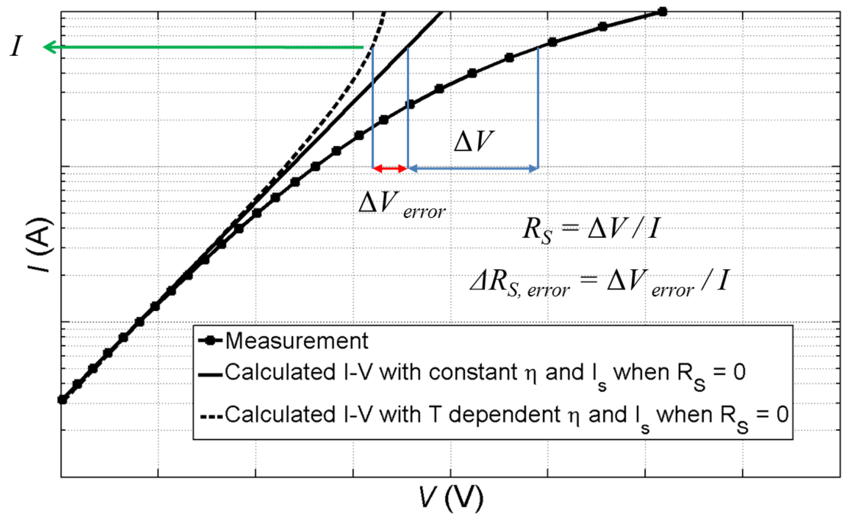

Fig. 1: Illustration of the thermally induced change in the I-V characteristics of a THz Schottky diode.

diodes or high frequency transistors. Secondly, infrared microscope cannot see through circuit metallization, prohibiting the direct measurement of the junction if it is covered by the metal, as is the case, e.g., in Schottky diodes. Third, infrared imaging cannot provide fast enough frame rate for the determination of thermal impedances or thermal time constants of the chip.

3 Reliability issues

Defect mechanisms can be divided into failure mechanisms and degradation mechanisms. Both of these can be induced by an excessive junction temperature. A typical example of a failure mechanism is the destruction of a device, which can occur, for example, when increased temperature causes increase in the device current and this in turn causes the temperature to rise even more until the device is destroyed.

An example of a degradation mechanism could be, e.g., a change in the electrical parameters of the device. An effect closely related to this degradation mechanism is the change of the electrical parameters of the device under unexpected self-heating. As demonstrated in Fig. 1 for a THz Schottky diode, the self-heating of the device changes the I-V characteristics of the device, which makes it more difficult to detect a real change in these parameters. This problem of accurately determining the electrical parameters of a device also complicates the design process.

4 Evaluation of mixer and multiplier diodes for MetOp-SG satellite mission

Among the instruments carried by the European Space Agency's MetOp Second Generation satellites are three, which employ Schottky diodes for frequency conversion and generation. In order to ensure the operational life time and performance requirements, a comprehensive reliability assessment for the diodes is performed well before the fabrication of the in-orbit instruments. This reliability assessment includes thermal characterisation of the diodes. The thermal characterisation has three goals: first, the determination of the maximum temperature during normal operation conditions. Secondly, the verification of the sufficient heat flow path in order to keep the diodes in the wanted temperature range throughout the mission, and third, the determination of the effect of heating on the electrical parameters of the diodes.

In order to perform these test, electrical test methods described in [1],[2] are used, although slightly modified to cope with the very fast thermal time constants of the diodes. In addition, an in-house developed method [3] is used to verify the results.

5 Conclusions

Thermal characterisation is an important part of the reliability tests of semiconductor devices. This is especially the case in applications which has to operate a long periods of time without the possibility of repair or replacement, such as satellite instruments. The typical thermal characterisation methods for semiconductor devices have been explained and the special case of thermal characterisation of THz Schottky diodes for MetOp-SG satellite mission is discussed in more detail.

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