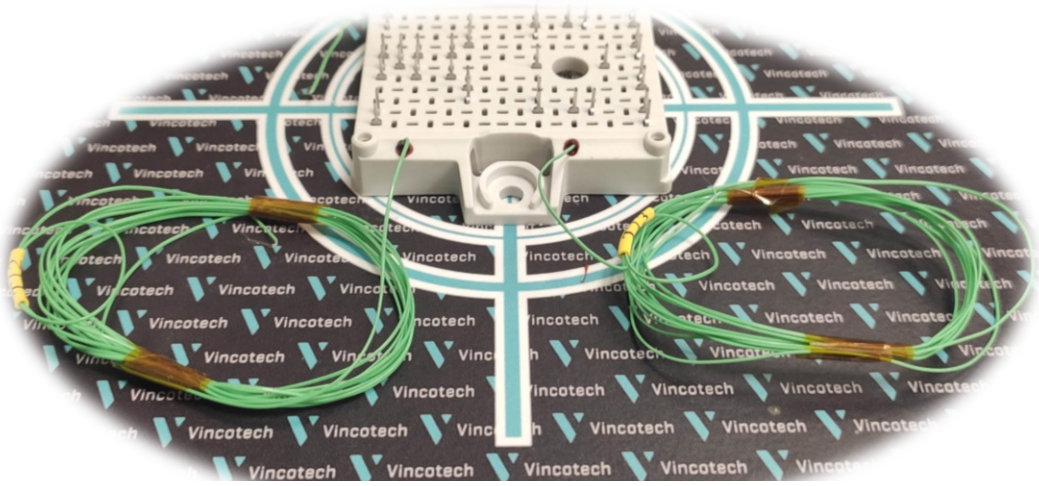
Vincotech

Chip temperature sensing methods for power modules

A look at thermocouples and thermal camera imaging to measure temperatures in a power module



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Revision history

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1 Abstract

This paper describes verification methods for semiconductor junction temperature during the design of power electronic devices. It presents two different temperature measurement methods, namely thermocouple and infrared camera. This document explains the differences between both methods and provides practical information for performing measurements. Beyond that, it explains how specially prepared power modules for temperature measurements can be ordered.

2 Introduction

The knowledge of the actual virtual junction temperature at a given operation point is essential for design validation, performance optimization and setting proper over temperature protection limits during the design of power electronic devices. The power module datasheet provides limits for the junction temperature under operation, but in practice reliability requirements limit the temperature to much lower values. During the design validation the actual junction temperature shall be compared to the simulated or calculated one ensuring the proper modelling of the thermal path and cooling system. Omitting this important validation step can result in a reduced service life or even malfunction of the power electronic equipment.

3 Limitation of integrated temperature sensors

Almost every Vincotech power module includes an integrated temperature sensor (NTC or PTC type) assembled on the DCB. Depending on the position of the temperature sensor, the module layout, the cooling conditions (natural convection, forced air or water), heatsink properties (material and geometry), distance to neighboring modules and the actual operation point the measured temperature of this sensor may significantly differ (see reference [1] and [3]). In any case the integrated temperature sensor does not show the actual semiconductor junction temperatures. The sensor can be used for over temperature protection (see reference [2]) and junction temperature estimation based on the thermal equivalent circuit of the power module.

In cases where the integrated temperature sensor is used to determine the semiconductor temperature a deep understanding of the system thermal properties is required. It is recommended to map the highest semiconductor junction temperature for the

worst case operation condition to the temperature measured by the integrated temperature sensor for that particular condition.

4 Chip temperature measurement with thermocouples

Thermocouples allow the chip temperature to be measured inside the enclosure of the power electronic equipment. Minor mechanical modifications might be needed to bring the thermocouple cables from the power module to the outside of the enclosure for connection with the measurement equipment. The thermal boundary conditions can be the same as those in the end application.

Thermocouples are used to measure the temperature based on a temperature-dependent voltage due to the thermoelectric effect (Seebeck effect). The Seebeck effect describes the occurrence of a voltage in an electrical conductor caused by temperature differences. This voltage signal is in the range of several µV. Different types of thermocouples are available. Well known types are the K- and T-type. The K-type (chromel-alumel) is the most common type with a typical sensitivity of 41 µV/°C, the T-type (copper-constantan) provides a typical sensitivity of 43 µV/°C.

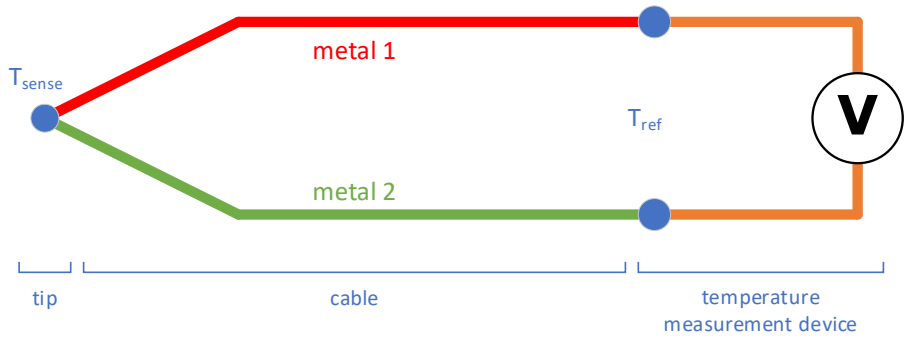

Figure 1: Thermocouple measurement configuration

The thermocouple tip is attached with a small amount of adhesive on the semiconductor top surface as close as possible to its middle section. The function of the adhesive is to keep the thermocouple tip in place and provide some basic resistance against vibration during transportation. However, in order to keep the influence on the measurement as low as possible, the adhesive amount used is small. The thermocouple is fed through a hole in the plastic housing to the outside (Figure 2). Additional adhesive is applied at the hole to ensure proper ruggedness against external pull force on the cable. Nevertheless, the thermocouple cable should be handled with care and excessive pull force should be avoided during handling and assembly of the module.

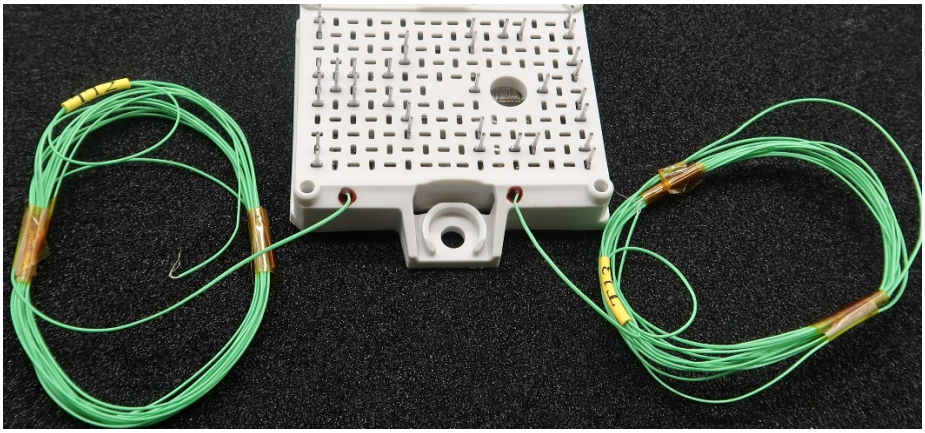

Figure 2: Power module with thermocouple cables fed through the housing and fixed with adhesive

The tip of the thermocouple is directly attached to the surface of the semiconductor. Do not touch the bare wire in order to avoid electrical discharge (ESD). Furthermore, the thermocouple cables are exposed to high voltage and the measurement equipment (e.g. data logger or hand held device) needs to be selected to withstand high voltages and shall provide sufficient isolation capability between the input channels and additionally from each input to protective earth (PE) or touchable parts of its enclosure.

The methods described are intended for use in laboratory settings only and must be used by qualified and trained personnel familiar with all applicable safety standards. The power module can be life-threatening due to high voltages.

In most cases there is at least one thermocouple connected to the switching node of the circuit. In the equivalent circuit diagram (Figure 3) this is represented by thermocouple TC1. The switching node has a parasitic capacitance to PE and the data logger can also have parasitic capacitances to PE. It can be seen that those capacitances form a path for common mode currents originated at the switching node. This representation is very simplistic, since neither driver and control circuits nor power source and load are included, but helps to provide a basic understanding. Good practice to avoid common mode interference is to mitigate C4 and C5 by using handheld equipment. If this is not possible, the common mode interference can be reduced by using HF-isolating transformer for the data logger power supply.

In a few cases the data logger or temperature measurement device is still affected by EMI and therefore can’t provide proper temperature measurements. For these cases Vincotech offers thermocouples with an adhesive layer between semiconductor surface and the thermocouple to isolate the thermocouple from the chip surface. This thin isolation layer can’t

be considered as safety isolation. The adhesive electrically disconnects the thermocouple from the semiconductor surface. Capacitance C1 (Figure 3) represents the capacitance created by the adhesive layer between semiconductor T1 and thermocouple TC1. The additional adhesive layer will add a negative offset to the measured temperature and slow down the dynamic response due to the additional thermal capacity.

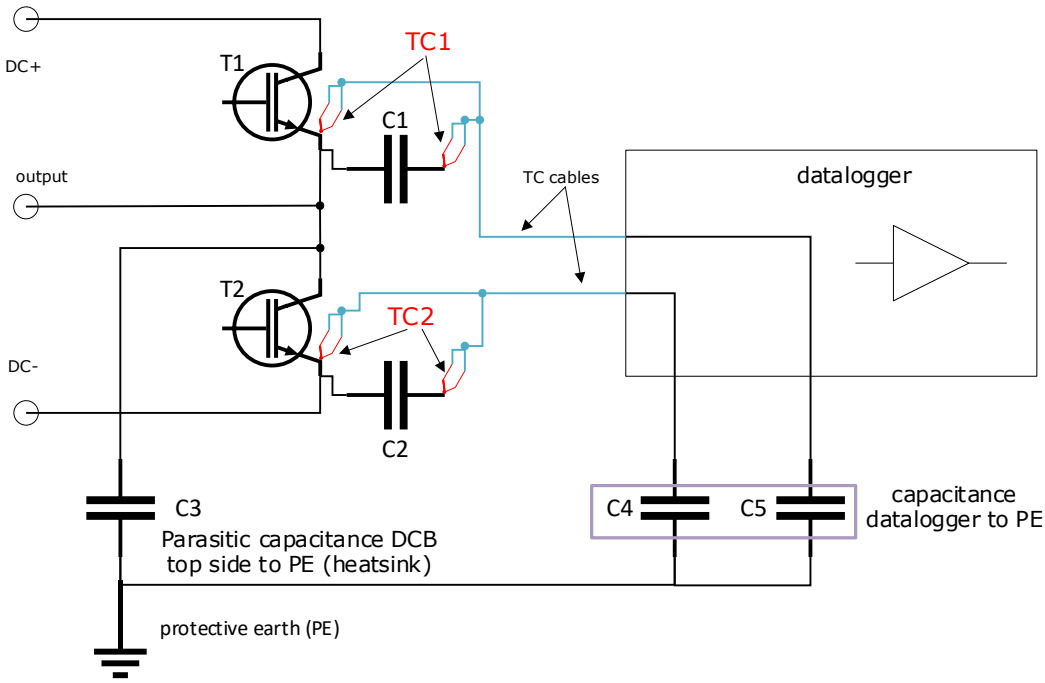

Figure 3: Equivalent circuit diagram of half bridge including parasitic capacitances of thermocouples and data logger

The following guidelines provide some basic hints to secure the correct functionality of the thermocouple measurements. In general, careful handling and assembly is recommended.

- Recommended maximum thermocouple cable length is 2 m
- Maximum 2 thermocouples per power module are recommended (if more locations need to be measured, more modules with different thermocouple locations should be ordered)
- Don’t twist cables of different thermocouples together
- Ensure sufficient isolation capability of the measurement equipment
- Avoid mechanical stress (e.g. pull-force) on the TC cables
- Use of ESD protective equipment is recommended

To order modules with thermocouples for temperature measurement please contact your regional sales representative or responsible FAE. In addition to the product part number, the following information is required:

- Identifiers of the chips to which the thermocouples shall be attached
- Type of thermocouple (K- or T-type)
- Length of the thermocouple cable
- Preferred location where the thermocouple cable leaves the housing (e.g. housing top-, left- or right-side. The default location is the housing top side)

5 Chip temperature measurement with infrared camera

Temperature measurement with infrared (IR) or thermal cameras provides high accuracy and fast transient response (if supported by the camera used), but also requires additional preparation of the system for the measurement. To allow IR camera measurements Vincotech provides power module samples with openings in the top part of the plastic housing and black painted chips. These power modules don't contain silicone gel and therefore don't comply with safety isolation standards. The locations of the openings in the housing are determined by the locations of the chips being monitored.

The methods described are intended for use in laboratory settings only and must be used by qualified and trained personnel familiar with all applicable safety standards. The power module can be life-threatening due to high voltages.

The lack of silicone gel requires limitation of applied test voltage at final electrical test to less than 800Vdc.

The black painted module (Figure 4) is assembled into the PCB, which contains a cut-out above the module. There can be one wide cut out as shown in the picture, but also smaller ones matching the size of the module cut-out can be used. In the latter case the image capture with the IR camera needs to be done at right angles to ensure a proper view of the IR camera to the chip.

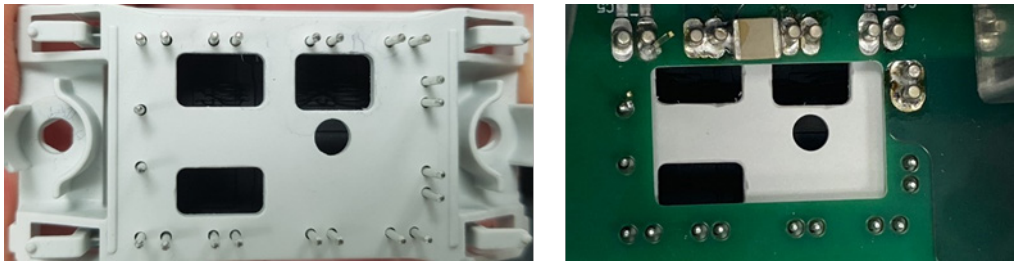

Figure 4: Black painted module with opening in housing (left) and assembled black painted module in PCB with cut-out (right)

For temperature measurement the IR camera is placed to allow direct sight of the semiconductor (Figure 5). If the module and PCB are assembled in an enclosure it is necessary to either remove it completely from the enclosure or provide openings in the enclosure as well. The distance between camera and module is determined by the number of chips to be measured and the required resolution.

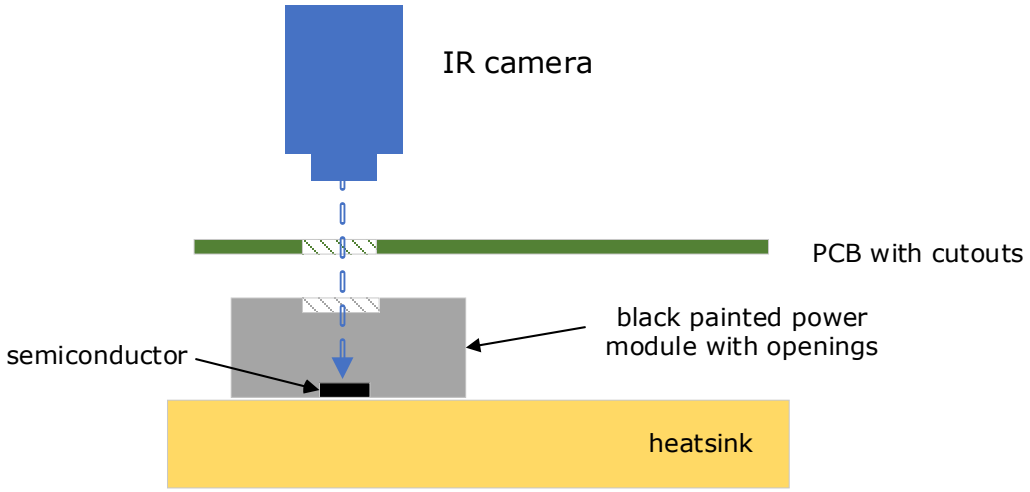

Figure 5: Measurement setup with black painted module, PCB with cut-out and IR camera

The IR camera can either provide an overview picture showing all chip temperatures of interest (Figure 6) or display a more detailed picture to also analyze the temperature of bond wires. Typical IR cameras allow multiple temperature measurement presets e.g. temperature measurement of multiple pre-defined fixed points or definition of the maximum temperature (hot spot) in a defined area.

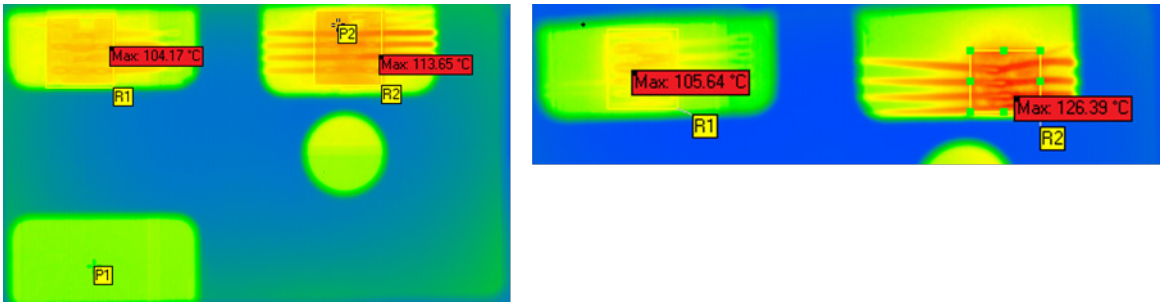

Figure 6: IR camera picture of black painted module during operation (left) and IR camera picture (zoom) with indication of highest chip temperatures (right)a

To order black painted modules for IR camera measurement please contact your regional sales representative or responsible FAE. In addition to the product part number, the chip to be monitored shall be indicated.

6 Summary

During the development of power electronic devices, which include power modules, the knowledge of the semiconductor junction temperature is essential for proper design validation and to ensure operation inside the limits given either by maximum ratings or reliability considerations. This technical paper described the junction temperature measurement principle and measurement setup with thermocouples and with infrared camera. Depending on the surrounding system of the power module one of the methods might be more suitable and requiring less effort for preparation. For both methods Vincotech offers specially prepared modules, which are available through the regional sales channel.

7 References

All reference documents are available on the Vincotech website and can be downloaded from the "Support & Documents" → "Technical Library" → "Thermal Management" section.

[1] Thermal Resistance, Thermal Spreading and Temperature Measurement

[2] Thermal Measurement with an Integrated NTC Thermistor

[3] Influence of Thermal Cross Coupling at Power Modules