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Internal processes in power semiconductors at virtual junction temperature measurement

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ABSTRACT

High measurement accuracy is the basis for a precise determination of the junction temperature T_j. Temperature measurement can be performed by means of temperature sensitive parameters (TSP) using the V_{CE}(T)-method, however, internal semiconductor processes like the removal of stored charge in bipolar devices have to be respected. The aim of this work is to determine the earliest time point of accurate measurement t_{MD} after switching off, as well as dependencies on device voltage classes and applied battery voltage. Measurement results are confirmed by performing the simulation with Sentaurus TCAD. Dependencies of delay t_{MD} on temperature, applied measurement current and battery voltage are demonstrated for IGBT and silicon diode.

1. Introduction

The virtual junction temperature T_{vj} is of great importance in the design of power electronic systems as the temperature swing ΔT_j influences lifetime with a power of −4.4 up to −5 as described by the lifetime models [2–4]. Therefore, it is the most critical parameter determining the accuracy of the results in power cycling tests. During conduction mode, the base width w_B of bipolar devices like IGBTs and diodes is modulated. After switching off the device, the charge carriers have to be removed. This requires the adherence of a delay t_{MD} before the temperature measurement can be executed. The measurements of T_{vj} using V_{CE}(T)-method [1] without considering the measurement delay t_{MD} can lead to a notable inaccuracy in lifetime estimation [5,6].

2. Measurement setup and results

2.1. Test setup passive switching

A test setup as shown in Fig. 1 was used to measure the delay t_{MD} after switching off a single pulse. The DUT remains in ON-state by applying a 15 V bias between gate and emitter whereas an auxiliary device either IGBT or MOSFET switches the circuit on and off.

For measurement, the driver controlled auxiliary switch is turned on for 420 µs in accordance with the flooding time of the device under test (see switching pattern in Fig. 2). The load current of 180 A (90% of the rated current) is achieved by the applied DC voltage 600 V and an adjustable load inductance of 1–4 mH.

2.2. Test setup active switching

For active switching the passive setup was customized with the opportunity to control the device under test with its own driver. Furthermore, a V_{CE}-clamping circuit, paralleled to the DUT, complemented the circuit to enable precise V_{CE}-measurement despite high V_{CE}-voltage before switching on the circuit and after turning off. Detailed information of the applied circuit is given in [5].

2.3. Measurement results

Fig. 3 depicts the measurement delay for a 4.5 kV IGBT during passive turn-off at two different temperatures. At 298 K a delay t_{MD} of approximately 180 µs to the initial value of collector-emitter voltage V_{CE} and around 270 µs for the measurement at 398 K can be observed. From Fig. 4 the delay values of about 230 µs, 250 µs, 270 µs and 300 µs at applied measurement currents of 10 mA, 25 mA, 50 mA and 100 mA can be seen, respectively. Fig. 5 shows the measurement delay for a 3.3 kV EMCON diode during turn-off without reverse voltage. The delay t_{MD} of approximately 70 µs at 298 K and 130 µs at 398 K were monitored. This measurement was performed by applying a

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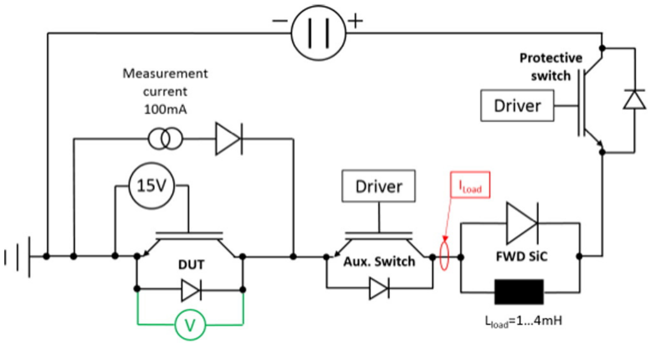

Fig. 1. Schematic illustration of the test setup for passively switched DUT.

Fig. 2. Switching pattern for passive switching.

measurement current of 100 mA due to the not negligible leakage current at high temperature.

3. Simulation setup and results

3.1. Passive switching

The investigation focussed on two different operating conditions. First, switching off the DUT to an application specific high battery voltage which is called active switching. Second, the device is switched off passively using an external switch as in standard power cycling tests. Two dimensional model was designed for a 3.3 kV EMCON diode with a rated current density of 65 A/cm^2 and a 4.5 kV planar cell IGBT with a rated current density of 36 A/cm^2.

Fig. 6 shows the simplified circuit containing a time dependent current source, a DUT and a voltage source which is continuously supplying 15 V to the gate of the IGBT. During the passive turn-off, the influence on

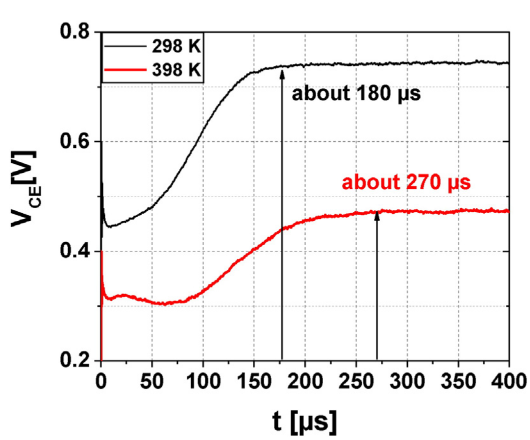

Fig. 3. Measurement delay for 4.5 kV IGBT during passive turn-off at two different temperatures, I_{load} = 45 A, I_{meas} = 25 mA.

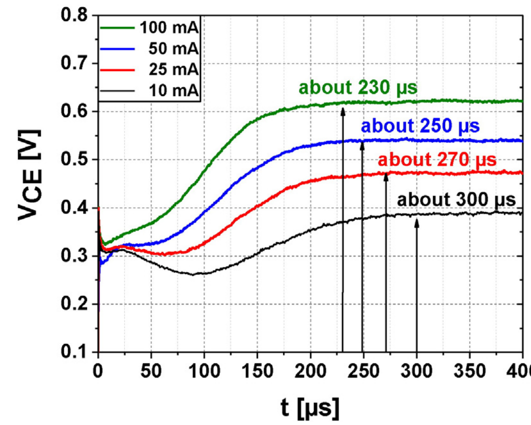

Fig. 4. Measurement delay for 4.5 kV IGBT during passive turn-off with different measurement currents. I_{load} = 45 A, I_{meas} = 25 mA, T = 398 K.

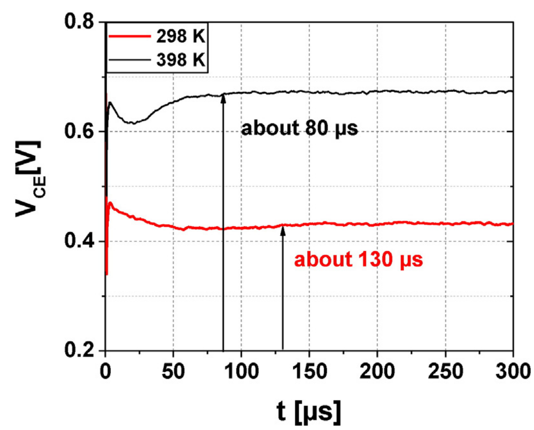

Fig. 5. Measurement delay for 3.3 kV EMCON diode during passive turn-off, at two different temperatures, I_{load} = 58 A, I_{meas} = 100 mA.

the measurement delay was investigated using Sentaurus TCAD. In the physic section of the device simulator, the UniBo model was selected as the low field model for doping-dependent mobility in the device simulator. At high electric field, the electric field dependent mobility Canali model has been used. Additionally the band to band Auger recombination and Shockley-Read-Hall recombination model were also implemented in the physic section.

The passive simulations was performed by changing various parameters like temperature (T), measurement current (I_{meas}), load current (I_{load}) and duration of I_{load}. The measurement delay t_{MD} is the duration from the I_{load} turned off to the point where the V_{CE} reaches its steady

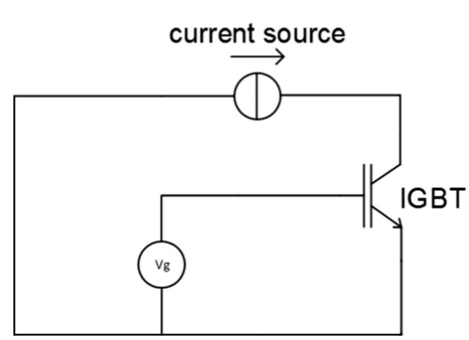

Fig. 6. Circuit schematic for the IGBT passive turn-off simulation.

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