SILICON CARBIDE DEVICES CHARACTERISATION SYSTEM

Laurenţiu TEODORESCU[1], Andrei-Sorin GHEORGHE[2]

Abstract. *The measuring results of some commercial wide band gap semiconductor devices by using a characterisation system which may work between* 50-80ºC *are presented in this paper. There are described the system blocks and the control software. The temperature characterisation system has a DC power supply furnace and a semiconductor device characterisation system as main components. The obtained data files may be easily processed, being in .xls format, and device characterisation may be done with proprietary measuring software.*

Keywords: silicon carbide devices, temperature characterization system, wide band semiconductors measurement

1. Introduction

Wide band semiconductors are produced today to be used in high temperature environment to fulfil special tasks in a wide area of research and industry applications. In the last time we may observe a high interest to obtain devices working at high temperatures in aerospace and military industries, nuclear power plants, cement factories, siderurgy [1]. The purpose of this paper is the study of some commercial low cost silicon carbide Schottky diodes [2-5] using an own designed temperature characterization system. The main properties of this system are:

- I/V device characteristic is automatically done;
- voltage bias range: −200 V … +200 V;
- current limits: −1 A …+1 A;
- device temperature set range: 50°C and 800°C;
- absolute temperature set precision: better than 0.5°C;
- relative temperature measuring precision is 0.1°C;
- measured data is in .xls format;
- maximum time for device temperature stabilisation with a maximum 0.5°C deviation is 150 minutes for any temperature value;
- typical time for device temperature stabilisation with a maximum 0.5°C deviation is 90 minutes under 200°C.

We should notice that the maximum temperatures of the current silicon systems are lower than the working temperatures of the designed system. A main problem comes when we talk about encapsulating high temperature semiconductor devices.

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Due to different temperature coefficients of the bonding material and the silicon carbide device, the welding breaks at high temperatures. It's the designer interest to find out potentially weak devices before they are used in the final product.

2. The Characterization System

2.1. The block diagram

The block diagram of the characterisation system which will perform I-V characterization of SiC devices at different temperatures is given in Fig. 1.

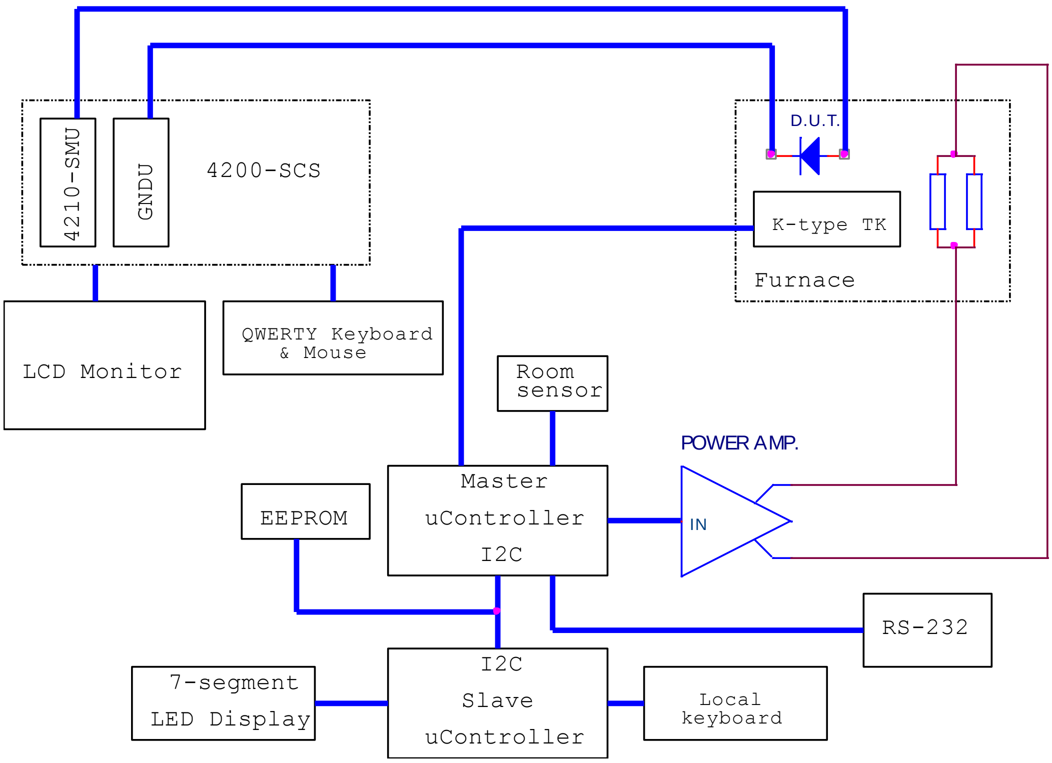

Fig. 1. The block diagram of the characterisation system.

The system consists in (Fig.1):

a) semiconductor characterisation system 4200-SCS (Keithley) [6].

b) furnace with Kanthal heating resistors, a K-type thermocouple with DUT (device under test) mounted inside it;

c) control and supply unit [7] which comprises:

– a custom made high efficiency DC power amplifier;

– the interface unit which sets and monitors the furnace temperature;

– one control unit which measures temperatures and drives the DC power supply;

– EEPROM (Electrically Erasable Programmable Read-Only Memory);
– room temperature sensor.

Except the 4200-SCS, all another hardware units mentioned above have been manufactured in the laboratory.

2.2. The software

The system has the following software components:

– the measurement software made by Keithley Instruments Inc.;
– the furnace control software developed in C language;
– the furnace characterisation software developed in C++ [8] and Matlab [9].

2.2.1. The measurement software

The measurement software used for devices characterisation is KITE (Keithley Interactive Test Environment, Fig. 2). This facilitates interactive characterization of the DUT without knowing any programming language on the user side. KITE consists of a variety of graphical user interfaces (GUIs) that allow customized ITMs (Interactive Test Modules) to be developed through Project Navigator. The device plan defines and sequences all tests for the DUT.

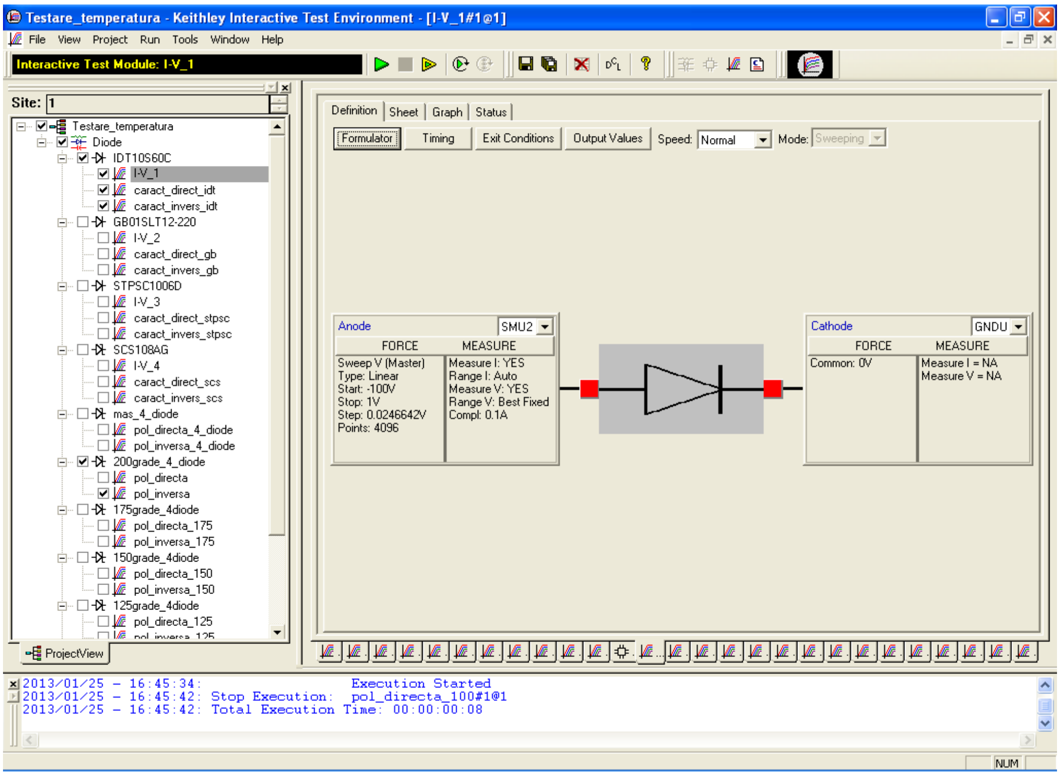

Fig. 2. Keithley Interactive Test Environment.

In KITE are defined the following parameters (Fig. 2):

a) DUT connections with semiconductor characterisation system setting;

b) Forcing functions (Measure Options) for the device:
- type of the signal applied to DUT: voltage sweep;
- voltage range (-100÷1 V);
- maximum anode current absolute value (Compliance set to 0.1A);
- voltage step (0.02 V).

c) ITM timing speed and output recorded values (speed is set to Quiet).

Output data file (sheet tab) may be also saved in excel format.

2.2.2. The furnace control software

This software handles the following tasks:

a) I2C (Inter-Integrated Circuit) bus communication between Master Microcontroller, Slave Microcontroller and EEPROM memory (Fig.1);
b) Relative temperature reading from K-type thermocouple;
c) Room temperature reading;
d) Data processing;
e) Absolute temperature display and temperature programming inside the furnace;
f) Power amplifier driving;
g) Data transmission through serial port.

The source code is written using Silicon Laboratories IDE from Silabs and ICCAVR from ImageCraft Creations Inc.

2.2.3. The furnace characterisation software

Furnace characterisation software handles computer data acquisition through RS232 port (Fig. 1) using Microsoft Visual C++ environment and data display through Matlab. The data acquired from serial port will be stored in a text file. The text file contains 8-bit command value given to power amplifier input and furnace temperature value. Recorded data will be displayed in Matlab.

2.3. The hardware

2.3.1. Keithley semiconductor characterisation system (4200-SCS) [6].

This unit (Fig. 1) is a computer-based data acquisition system used for our devices characterisations. The following modules are used for measurements:

a) 4210 SMU (Source Measure Unit) which permits extended range (-1 A ÷ +1 A) in current measurements, connected to the anode of the DUT;
b) GNDU (Ground Unit), connected to the cathode of the DUT.

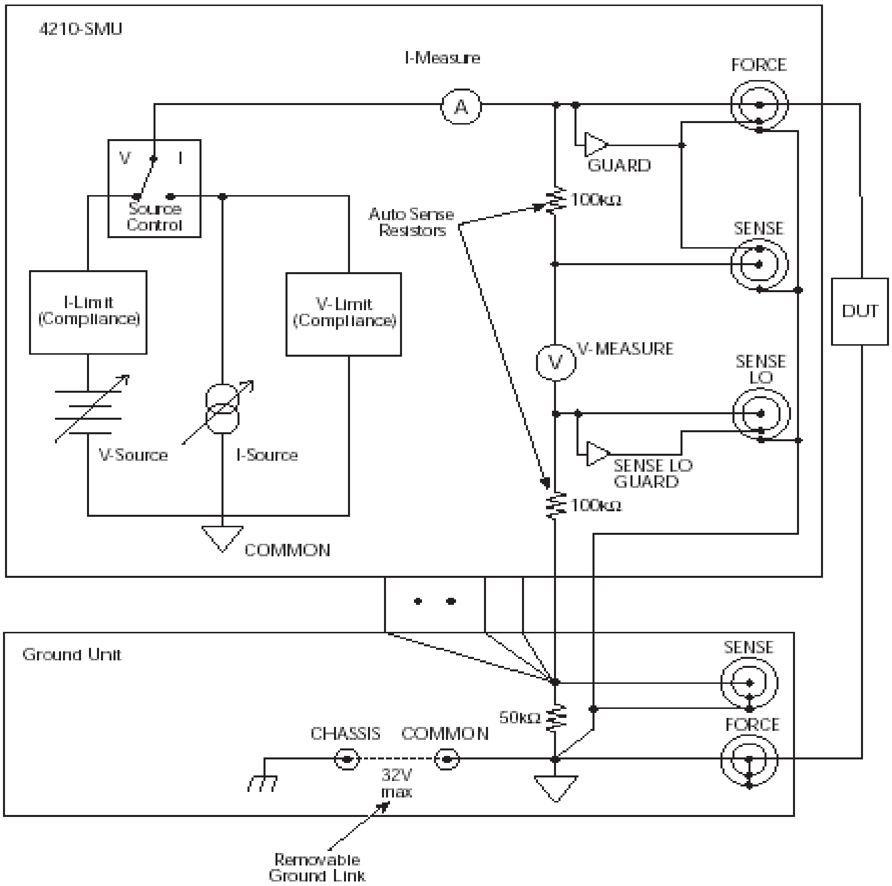

Fig. 3. DUT measurement configuration [6].

The measurement configuration is given in Fig. 3. 4210-SMU has built-in V and I programmable sources with overload protections and a high resolution amperometer which permit device I-V characterisation. Only V-Source and the amperometer are used here for DUT measurement. The sense guard circuit is not used during measurement. DUT is connected between force connectors of 4210-SMU and GNDU. Both connections with DUT are made through triax cables in order to allow low signal measurements.

2.3.2. The furnace

The devices characterization furnace is shown in Fig. 4. Actual configuration permits to measure up to 4 diodes. If more temperature-resistant wires are attached to the unit, this number can be increased up to 10-20 devices.

DUT's are mounted on a U frame metallic holder, at distance from heating elements. Because of this, we have a large thermal inertia which was solved by the software in a special manner (furnace temperature prediction). K-type thermocouple will be fixed as close as possible by the DUT's, to permit accurate measurements. Heating resistors are mounted on the side walls. There are made from Kanthal, an iron-chromium-aluminium (FeCrAl) alloy which operates at high temperatures (up to 1300ºC).

The furnace is supplied and controlled by a system with the following parts:

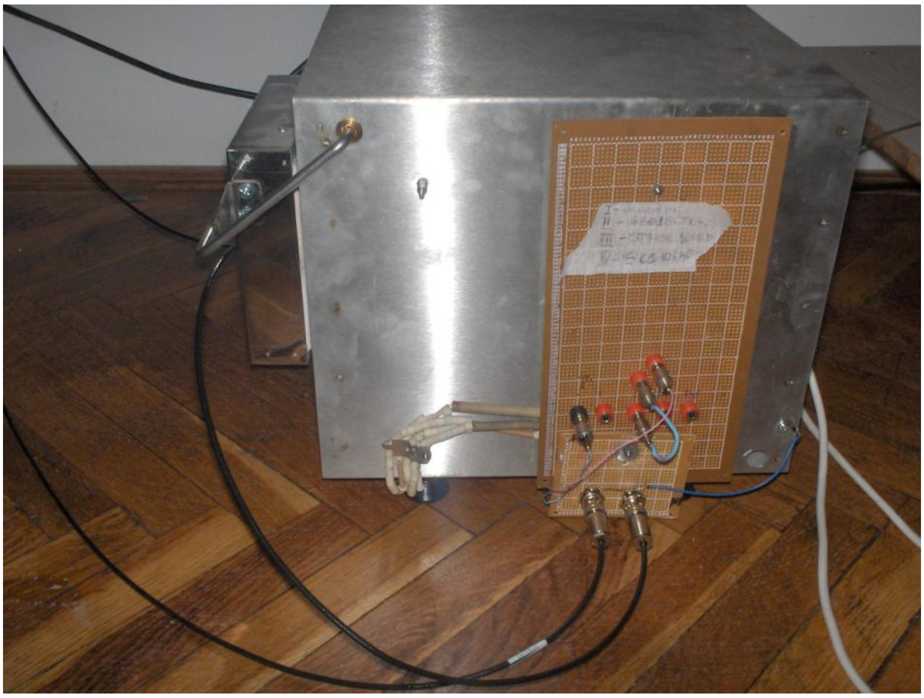

Fig.4. The manufactured furnace.

The power amplifier

This unit [7] consists in a 1 kW DC voltage feedback power amplifier. Its main functions are to supply the heating elements. A low electromagnetic emission allows the small signal measurements.

The user interface unit

User interface unit [7] was designed for

a) DUT temperature display (inside the furnace);
b) DUT temperature set.

This unit consists in a I2C Slave Microcontroller, one 4-digits 7-segment LED display (Fig. 1) which shows temperature information and a 3 keys keyboard used to set temperature inside the furnace. The slave microcontroller will read data from keyboard and send it to master microcontroller through I2C bus. It also receives temperature value on I2C bus and displays it on LED display.

The control component

Control unit [7] has one I2C Master Microcontroller (Fig. 1) which communicates with Slave Microcontroller and EEPROM on I2C bus. It computes room temperature, DUT temperature and drives the power amplifier through its internal 8-bit DAC (digital to analogue converter). It also sends this information to a serial line-dual receiver to be sent through RS232 port to the computer.

EEPROM memory

The memory [7] stores K-type thermocouple temperature-voltage characteristic. It can be accessed on I2C bus. It returns on I2C the temperature value stored at the address where is located the voltage value.

3. The experimental measurements

The characterization system has been used to test 4 SiC (silicon carbide) commercial Schottky diodes produced by 4 different manufacturers [2-5]. The tests were done according with the following specifications:

a) Anode-catode voltage range (V_{AK}) is between -100V and +1V;
b) Anode maximum current values (I_{AK}) are set in -100mA/+100mA range;
c) Case temperature of the DUT may be programmed between $50^0C \div 200^0C$.

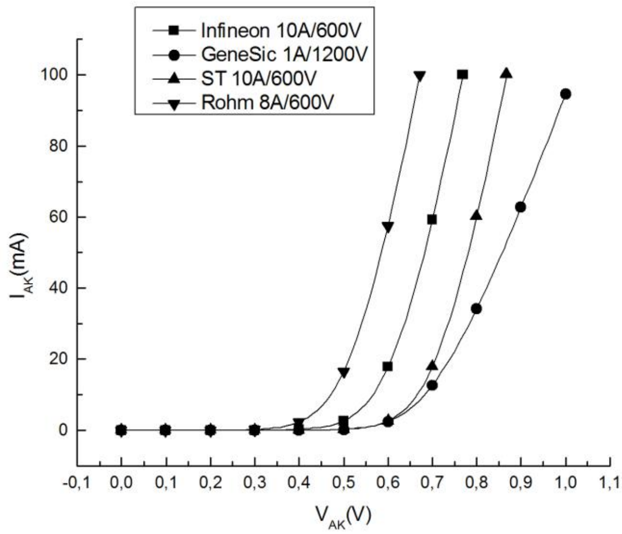

Fig.5. The SiC diodes forward characteristics measured at 200ºC.

The forward characteristics of the SiC diodes measured at 200ºC, are presented in fig. 5. Rohm diode [3] has the lowest forward voltage at the same current value. The GeneSiC [5] diode has a high series resistance.

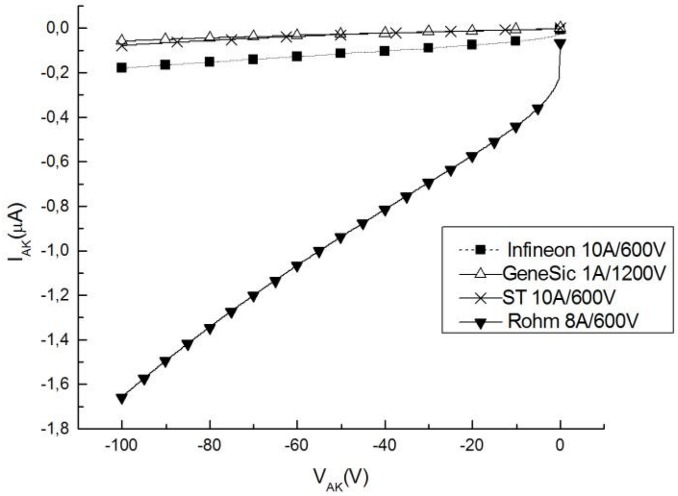

Fig. 6. The SiC diodes reverse characteristics measured at 200ºC.

In the reverse bias, the current value increases with the reverse voltage on Rohm diode [3]. In contrast, the reverse current values of the others measured diodes have lower values and are almost constant up to 100 V. The very low currents (in nA range) have been precisely measured due to the noise-free furnace DC power supply.

The diode performances are proved by a low forward voltage dropout and very low reverse currents. From the curves plotted in Figs. 5-6, we observe that Infineon diode [2] has a good performance. Therefore this diode has been measured at various temperatures in 50ºC÷200ºC range (Fig. 7, 8).

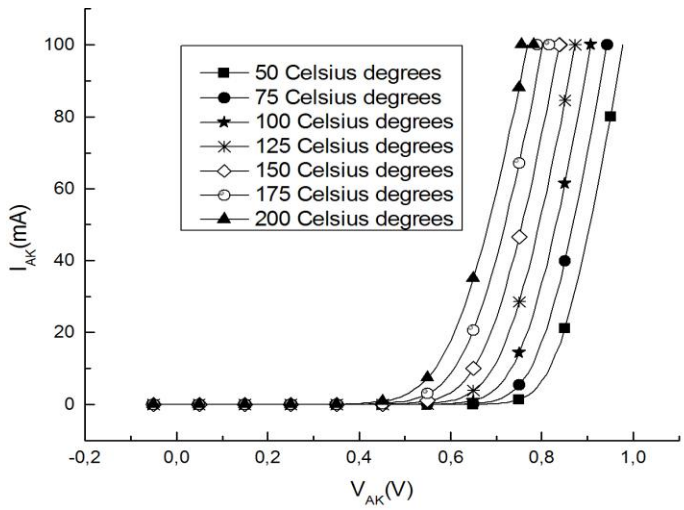

Fig.7. The forward characteristics of Infineon diode at several temperatures.

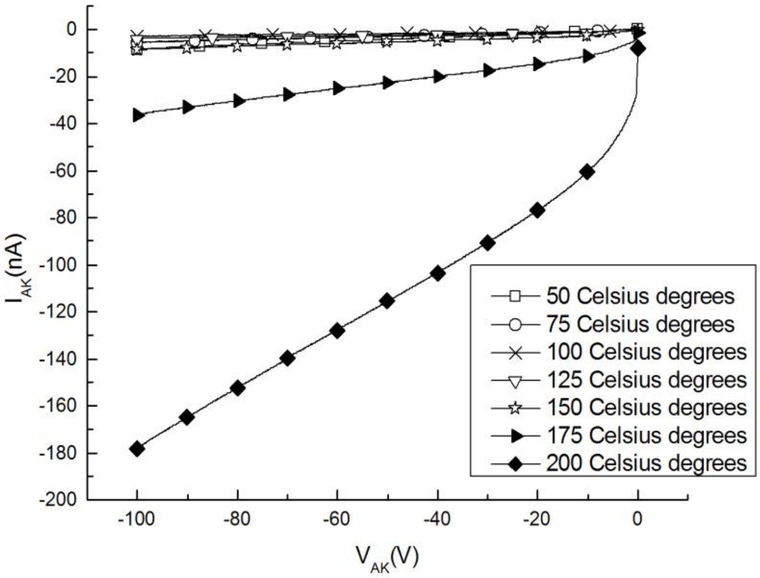

Fig.8. The reverse characteristics of Infineon SiC measured at some temperatures.

In Figs. 7 and 8 are shown the forward and reverse current-voltage characteristics measured at several temperatures. The forward voltage decrease when temperature grows at the same current value. The reverse current is practically constant to the voltage up to 150ºC. At higher temperatures, the current has a strong enhance to reverse bias (Fig. 8).

4. Conclusions

A high temperature automatic testing system for SiC and diamond devices characterization has been presented and tested. Some commercial SiC devices have been characterised by measuring the forward and the reverse I-V curves in 50ºC÷200ºC temperatures range. The measurements showed that this system is working properly.

The main advantages of the system are the temperature set precision in a wide range, the low noise of furnace power supply unit which allows very low currents measurements, and the possibility of the DUT testing at high temperatures during a long time.

R E F E R E N C E S

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