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HIGH TEMPERATURE AUTOMATIC CHARACTERIZATION SYSTEM FOR SEMICONDUCTOR DEVICES

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Abstract. *An automatic temperature characterization system for the wide band gap semiconductor devices is presented. The system works in a large temperatures range* (40-450 °C) *which is much more than the range of the present silicon temperature testing system. The paper describes the parts of the system and control software. The main hardware components of the system are a PC controlled oven and a picoammeter. The software component of the system is written in TestPoint and performs an automatic I-V characterization of the semiconductor samples. The obtained data files are in Excel format but it can be easy displayed with other graphical dedicated software. In the end of the paper there were presented measurements realized with the system on the few metal-glass cases that will be used to encapsulate SiC temperature sensor.*

Keywords: temperature testing, devices on wide band semiconductors, SiC temperature sensor

1. Introduction

The high temperature power devices and sensors developed on wide band semiconductor materials have been in a permanent development. Over ten years ago first SiC devices (Schottky diodes) started to be available on the market.

Most of the semiconductor manufacturer companies are making researches in producing materials and devices technologies to decrease the price of SiC devices. In the same time, strong researches are focused on devices on diamond.

After the laboratory phase, the manufacturing of the device needs additional simulation, not only to test them in an environment which is similar to their operational conditions, but also to check the resistance of the devices to the stress test. These additional tests are needed in order to identify potentially weak devices before they are used in the field.

In our opinion, temperature behavior testing is the most important, difficult and time consuming phase for semiconductor devices characterization.

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This paper is focused on automated high temperatures testing system for wide band semiconductor devices. This system is very important because the maximum testing temperatures of the wide band semiconductor devices is more up than the maximum temperatures of the present silicon systems.

The main characteristics of the system are:

- Testing temperature range: 40 – 450 ^{o}C.
- Maximum temperature ramp: 50 ^{o}C/min.
- Voltage bias range: 0 – 100 V.
- Measurement current range: 1.000 pA – 100 mA.
- Controlled by PC using the GPIB, Ethernet and USB ports simultaneously.
- The measured data is written in Excel format.

The temperatures testing system can be used only for encapsulated semiconductor devices, only.

2. Temperature automatic characterization system (TACS)

2.1. Block diagram

The components of the TACS are given in figure 1. This system performs I-V characterization of 2-terminal devices at different temperature thresholds. The system has two components: hardware and software. The hardware component consists in:

- Oven.
- V-Source/I-Meter.
- PC.
- Switch.
- Data acquisition system (DAS).

The software includes two components installed on the PC:

- an oven control software developed by the oven manufacturer.
- a custom made software which controls the DAS and V-Source/I-Meter and performs the I-V characteristic of the device under test (DUT).

The oven is used for testing the DUT in high temperature conditions. Different temperature thresholds and cycles can be set by means of the control software. When a temperature threshold is reached, the oven closes an output relay.

This output relay is connected to the input of the data acquisition system. The custom made control software monitors the input of the data acquisition system. When the closure of the output relay is detected, an I-V characterization of the DUT is performed by sending commands to and reading data from the V-Source/I-Meter.

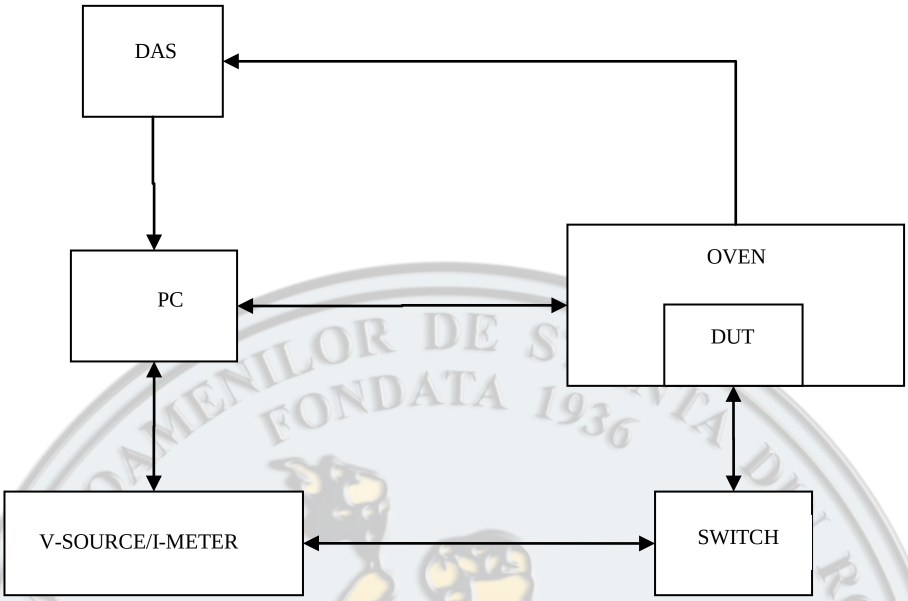

Fig. 1. Block diagram.

The V-Source/I-Meter is connected to the DUT through switch. This switch is used to select the device to be measured, when multiple DUTs are inserted in the oven chamber.

2.2. The oven

The oven is one of the most important parts of the system. It uses temperature controlled airflow for heating or cooling the DUT. The PC controls the oven by Ethernet card with dedicated software. The main oven characteristics are:

- Operating temperatures: 40-450 ^{o}C.
- Maximum temperature ramp: 50 ^{o}C/min.
- The temperature accuracy: 0.1 ^{o}C.

The oven contains several relays that can be switched automatically at the moments specified by the user in the oven control software. If the user superimposes the switching of the relay with the intervals where the temperature is constant, then he can synchronize the picoammeter with the temperature program and perform the automated measurement loop.

The temperature interface is simple and consists of two tables. In the first one, the user specifies the required temperature, time interval and temperature ramp with the oven ascend/descend at the required temperature.

In the second table, the user writes the moments of time when the relays switch taking into account the temperature program.

The DUT was mounted in a metallic holder. In the present we can test simultaneously 10 devices but this number can be increased. The metallic holder and the case type produce a thermal inertia that gives a delay between oven temperature display and real temperature of the holder-cases assemble. The displayed temperature will be reached at a later time because of the thermal inertia. In order to measure this delay and take it into account in the measurement process, we put on the case's holder a second calibrated thermometer probe.

The holder-cases assemble was insulated from oven by ceramic holders. The metallic terminal of the device was insulated by ceramic insulator, too. The devices can be tested independently or with common terminal (simplified electrical connection).

2.3. V-Source/I-Meter

The V-Source/I-Meter used in this system is model 4140B pA Meter/DC Voltage Source from HP. It comprises a high stability pA Meter with maximum resolution of 10^{-15} A and two programmable DC voltage sources. One of them can operate as unique staircase and accurate ramp generator. The range of the DC source is ±100V in 100 mV steps or ±10 V in 10 mV steps. The maximum current capacity is 10 mA [2].

The instrument can perform current measurement, I-V and C-V characterization, and high speed current measurement.

The 4140B can be operated locally or remotely controlled by means of the HP-IB interface. The HP-IB standard is an earlier version of the GPIB. Multiple instruments can be connected in the same time to a computer through the HP-IB interface. In order to identify the instruments in the HP-IB network, every interface must have a unique address. The address of the 4140B HP-IB interface can be set manually from the rear panel. The 4140B HP-IB card is connected to the PC GPIB card by means of a GPIB cable.

The PC can control multiple parameters of the 4140B by sending their specific program codes through the GPIB interface: type of function, range, integration time, filter, mode and current limit of the two voltage sources [2].

2.4. Data acquisition system (DAS)

The data acquisition system is model DI-158U from DATAQ. It has 4 fixed differential analog inputs, 12-bit A/D convertor and USB connection to the PC. The maximum input range is ±10 V [1]. The output relay of the oven is connected to one input of DI-158U. When the temperature in the oven chamber reaches a preset threshold, the output relay is closed and its voltage is sensed at the analog input of the data acquisition system.

2.5. PC

The role of the PC is to monitor and control the data acquisition system, V-Source/I-Meter and oven . It connects to the DAS by USB cable and to the oven by Ethernet. The PC has a Keithley KPCI-488 GPIB card which is used to communicate with V-Source/I-Meter. The GPIB (General Purpose Interface Bus) is an instrumentation interfacing method that simplifies the integration of instruments and computers into a system.

Two software applications run simultaneously on the PC. One application is used for configuring and controlling the temperature cycles of the oven. This application is created by the oven manufacturer.

The other application, called 4140B I-V, is custom made and is used for performing the I-V characterization of the DUT. This software will be described in the next section

3. 4140B I-V Software

We developed in TestPoint environment a software application that performs the I-V characterization of the DUT placed in the ovenchamber [3], [4]. This application monitors the analog input of the DI-158U, which is connected to the output relay of the oven.
When the temperature cycle reaches a threshold, the output relay is closed and the software detects the voltage increase at the DI-158U analog input.

At that moment, the software performs an I-V characteristic of the DUT by sending to the 4140B the DC voltage source values and reading the corresponding measured current values.

The I-V characteristic’s values are written in an Excel file for future analysis.

The 4140B application has a graphical user interface (GUI) composed of panels which allow the operator to log in, specify the Excel file in which the I-V data is saved, configure the 4140B parameters, configure and run the I-V test.

In the following paragraphs, each panel of the application is described.

3.1. Authentication

When the software is launched, the **Authentication** panel is shown (Fig. 2). Here, the operator must enter his password in the **Password** field in order to gain access to the application features.

If the password is wrong, an error message is displayed. If the password is correct, the **Authentication** panel is hidden and the **Data file** panel is displayed.

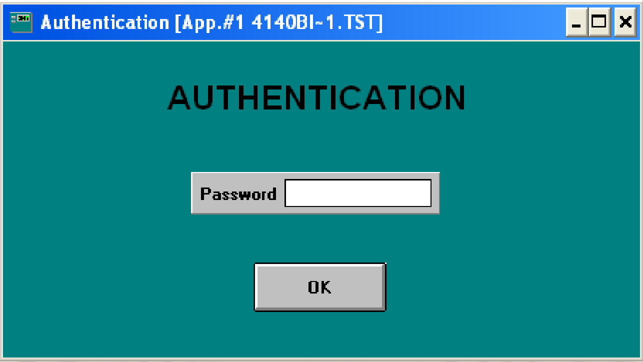

Fig. 2. Authentication panel.

3.2. Data file

The **Data file** panel (Fig. 3) allows the operator to select the Excel file in which the I-V test data is saved. When the **File** button is pressed, an **Open File** dialog window appears and the operator selects the desired Excel file. After the selection, the **Data file** panel hides and the **HP 4140B Configuration** panel is made visible.

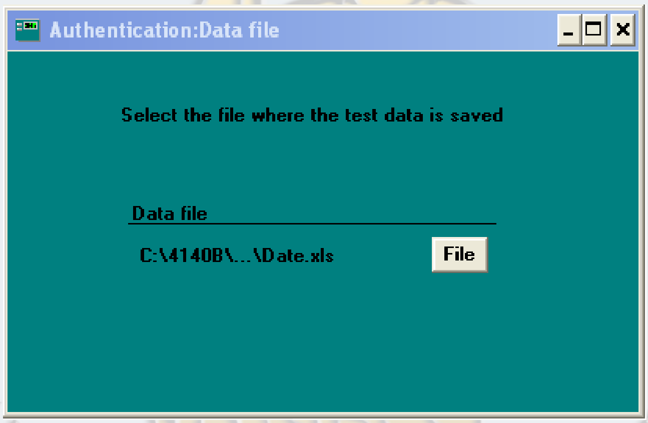

Fig. 3. Data file panel.

3.3. HP 4140B Configuration

In the **HP 4140B Configuration** panel the operator can configure the most important parameters of the HP 4140B (Fig. 4).

GPIB Address is a data entry field where the operator must specify the HP-IB interface address of the 4140B. All the other parameters are configured using dropdown lists which contain a portion or all their possible values. **Function** specifies the type of function performed by the instrument. In this software application, only one value can be selected, **I**, which configures the instrument for current measurement. **I Range** sets the range of the measurement. The operator can select auto range or one of the 11 fixed ranges. In case of auto range, the

Lower limit of AUTO mode can be specified. This parameter represents the lowest current range used by the auto range mode.

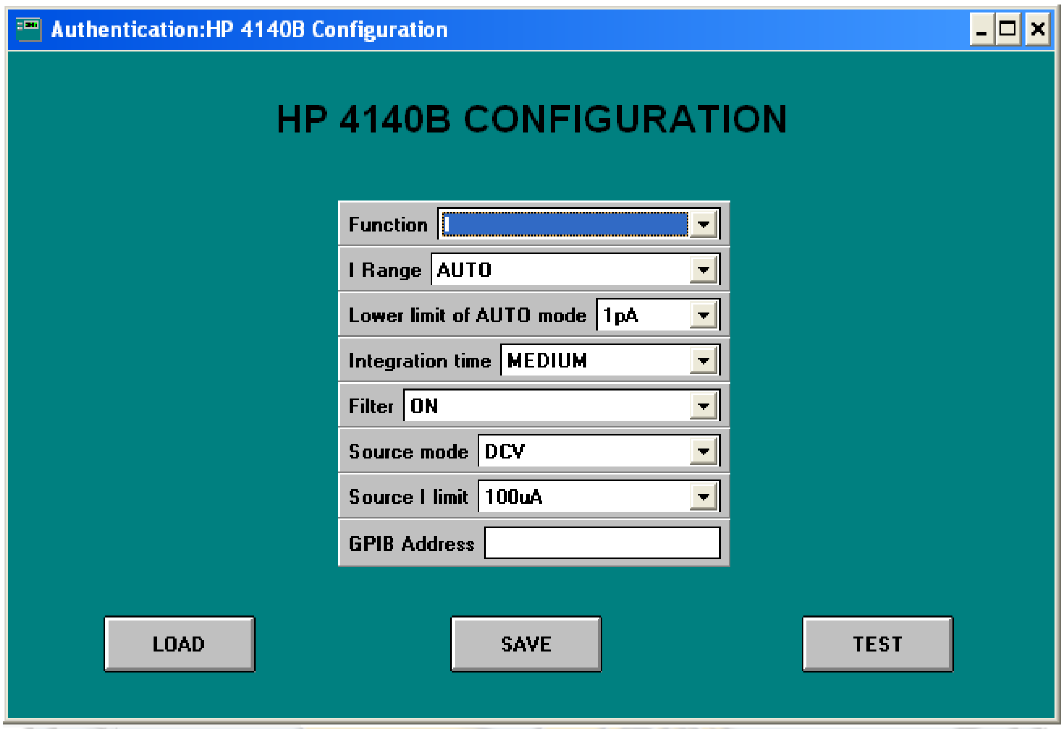

Fig. 4. HP 4140B Configuration panel.

The **Integration time** can have three values: **SHORT, MEDIUM** and **LONG**. A short integration time means the fastest measurements, but the lowest accuracy. A long integration time means the slowest measurements, but the highest accuracy. The medium integration time is a tradeoff between measurement speed and accuracy. **Filter** field allows the operator to choose whether or not to use the instrument's internal filter for rejecting AC noise. The voltage source used in the I-V characterization can operate in several modes. In this application, only the DC Voltage mode (DCV) is needed, which can be selected in the **Source mode** field. **Source I limit** configures the current limit of the voltage source.

The configuration can be saved in an Excel file by pressing **SAVE** button. Any prior saved configuration will be overwritten. The operator can load the last saved configuration by pressing **LOAD** button. The **TEST** button sends the configuration to the instrument through the GPIB interface hides the **HP 4140B Configuration** panel and shows the **Test Configuration** panel.

3.4. Test Configuration

The **Test Configuration** panel is illustrated in figure 5.

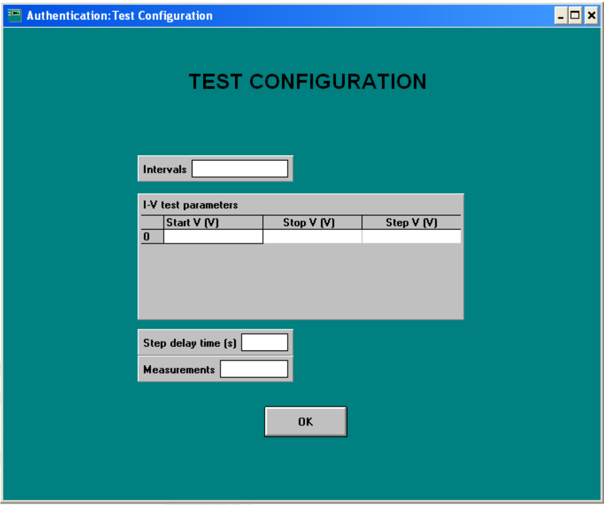

Fig. 5. Test Configuration panel.

In the **Test Configuration** panel, the operator specifies the I-V test parameters. The I-V test is performed by applying a linear voltage sweep at the terminals of the DUT and measuring the corresponding current values. The **Test Configuration** panel offers the possibility to split the voltage sweep domain in multiple intervals, each with a different voltage increment. Thus, some areas of the I-V characteristic can be investigated more thoroughly by using a smaller voltage step.

The operator can specify the number of intervals in the **Intervals** data entry field. In the **I-V test parameters** table the intervals are defined. For each interval, the start voltage **Start V (V)**, stop voltage **Stop V (V)** and voltage increment **Step V (V)** must be introduced. The current value of each I-V point can be obtained by performing multiple measurements and averaging the obtained values. The number of measurements taken for each current value is introduced in the **Measurements** field. **Step delay time (s)** represents the current settling time before each multiple measurement.

There are several conditions that need to be fulfilled in the **Test Configuration** panel. The step delay time and the number of intervals must be different from 0. The software automatically adjusts the number of rows of the **I-V test parameters** table so that it equals the number of voltage sweep intervals. Thus, all the table fields must be filled in. Also, the stop voltage of one interval must be equal to the start voltage of the next interval. The voltage increment must differ from 0 and the start voltage and stop voltage of the same interval must not be equal. The last condition is that the difference between the stop voltage and start voltage of every interval must be a multiple of the voltage increment. Thus, the number of I-V data points is integer.

When the **OK** button is pressed, all the above conditions are verified. If at least one of the conditions is not fulfilled, an error message is displayed. If all the conditions are accomplished, the **Test Configuration** panel is hidden and the **Test** panel is shown.

3.6. Test

The **Test** panel is illustrated in figure 6. It is divided in two sides: the upper area is designated to the signal received from the output relay of the oven and the area below is designated to the I-V characterization of the DUTs.

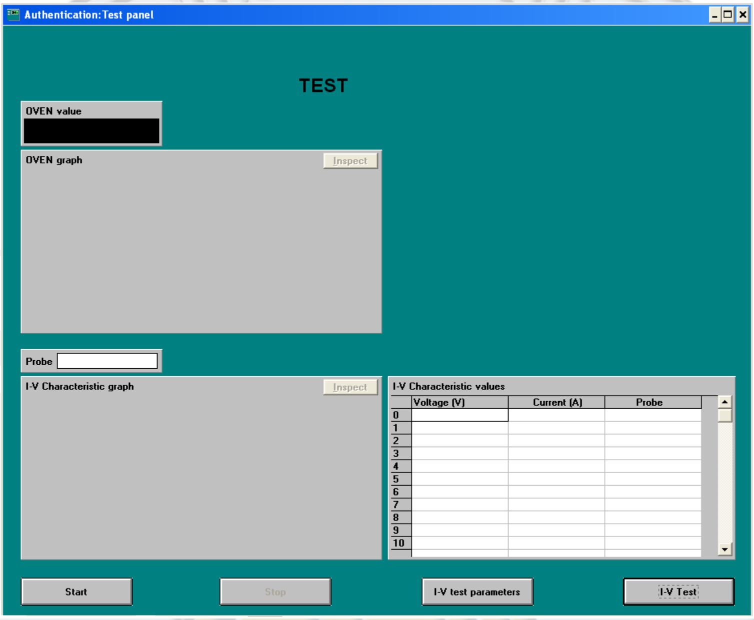

Fig. 6. Test panel.

The upper area contains the following objects: **OVEN value**, which displays the numeric value of the signal received from the output relay of the oven, and **OVEN graph**, which plots this signal with time.

In the area below, **Probe** is a data entry field in which the operator specifies the number of the DUT that is characterized. This field is useful when several DUTs are introduced in the ovenchamber and the switch is used to select the desired device to be tested. **I-V Characteristic values** is a table which contains the voltage and current values of every I-V characteristic point, and also the number of the analyzed probe. The **I-V Characteristic graph** displays the I-V plot.

There are four buttons which the operator can push. **Start** starts the acquisition from DI-158U, **Stop** terminates the acquisition, **I-V test parameters** shows the **Test Configuration** panel and **I-V Test** initiates the I-V characterization.

In order to begin the test, the operator must push the **Start** button. This action initiates the data acquisition from the DATAQ DI-158U input, where the relay is connected. The sample rate is 1kHz and every 100 samples are averaged. The result is displayed on **OVEN value** and plotted on **OVEN graph**. When the averaged value is greater than 1V, it means that the relay closed, signifying that the oventemperature cycle reached a threshold. At this moment, the acquisition from the DI-158U is stopped and the I-V test is initiated.

The first action of the I-V test is to clear the **I-V Characteristic graph** and the **I-V Characteristic values**. Then, the first voltage sweep interval from **I-V test parameters table** is extracted. The start voltage of the interval is output by HP 4140B and the current of the DUT is measured as many times as written in the **Measurements** field. The obtained values are averaged and the result, as well as the voltage value and the number of the probe are written in the **I-V Characteristic values** table. Also, the voltage-averaged current point is appended to **I-V Characteristic graph**. The next output voltage value is calculated by adding the voltage increment of the interval to the actual output voltage and the above measurement steps are repeated until all data points of the interval are measured. The above process, described for the first interval, is performed for all intervals introduced in **I-V test parameters table**.

At the end of the I-V test, the **I-V Characteristic values** table is saved in an Excel file, in a new worksheet, and the acquisition from DI-158U is started again.

The operator can perform another I-V test at the same temperature threshold by pressing **I-V Test** button. Thus, when multiple DUTs are inserted in the ovenchamber, all of them can be characterized. This possibility implies that the oven must be configured to keep the temperature threshold for a period greater than the one needed to perform all the desired I-V tests. Also, after the completion of every I-V characteristic, the operator can change the test configuration by pushing **I-V test parameters** button. The new configuration is used by the following I-V tests.

When the temperature cycles and all the desired I-V characterizations are finished, the operator can stop the DI-150U data acquisition by pressing the **Stop** button.

4. Experimental results

The system was used for temperature stress characterization of fully isolated packages that will be used for SiC Schottky temperature sensor diodes. The testing temperatures were in 50-400 ^{o}C range. The package was characterized by means of electrical measurements carried out during a thermal stress cycling test. In the preliminary tests, the temperature was varied between 300-400 ^{o}C for 500 cycles. For the next 500 cycles, the temperature range was 50-400 ^{o}C. In both situations, the temperature was changed with a rate of 50 ^{o}C/min. The temperature variation limits used in our experiments correspond to the values commonly used in operational conditions. The change rate exceeds the slew rate of the temperature from cement manufacture.

For characterizing the six fabricated capsules, the glass leakage current was measured at different temperatures and voltages, before and after the thermal cycling.

In the **HP 4140B Configuration** panel, the **I Range** was set to **AUTO** and **Lower limit of AUTO mode** to **1 pA**. In order to obtain the best measurement accuracy, the **Integration time** field was set to **LONG**, and to eliminate measurement noise, the filter was activated. The tests showed that, especially at high temperatures, a certain time is needed for the probe current to settle after the source voltage is applied. This period was determined empirically and has values over 30 seconds, which were specified in **Step delay time** field. The DUT was selected by means of the switch. The DUTs can be tested at a fixed voltage, by sweeping the temperature (voltage parametric curves), or at a fixed temperature, by sweeping the applied voltage (temperature parametric curves).

For example, the dependence of the leakage current on temperature and voltage at 1000 cycles is shown in figure 7.

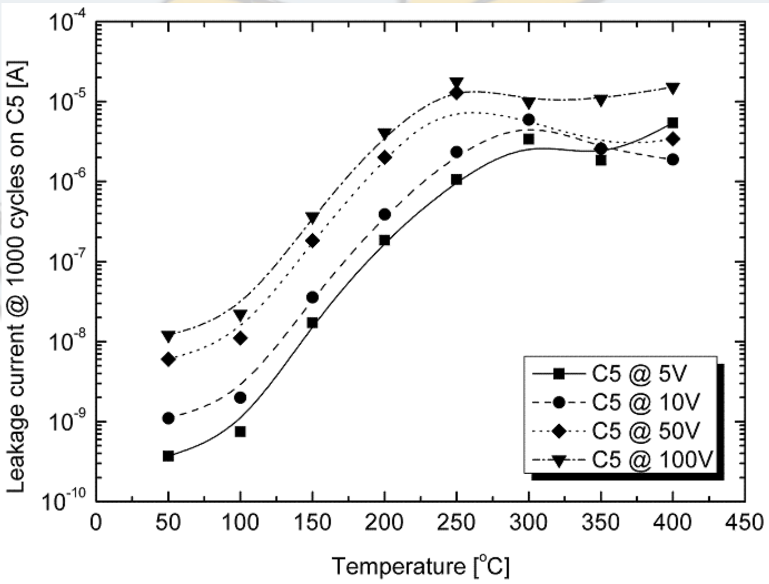

Fig. 7. Measured leakage current versus temperature at 1000 cycles for four voltage levels applied between the sensor terminal and package capsule: 5 V, 10 V, 50 V and 100 V.

The data from figure 7 was measured on a single capsule with a 50 ^{o}C temperature step. The leakage current increases with temperature and applied voltage.

At higher temperatures, the current-temperature variation rate drops significantly. The thermal stress cycles have small influence on the leakage current. For low voltage levels, the leakage current level is acceptable, even at high temperatures. It can be noticed that the SiC SBD sensor is biased at voltages below 5 V and at a current in the mA range. The thermal cycling does not produce strong mechanical stress. The SEM image of the thermally stressed capsules (Fig. 8b) does not show major glass modifications or degradations compared to the glass of the capsules which were not thermally stressed (Fig. 8a).

(a) (b)

Fig. 8. SEM micrography of the case glass: (a) initially; (b) after 1000 cycles.

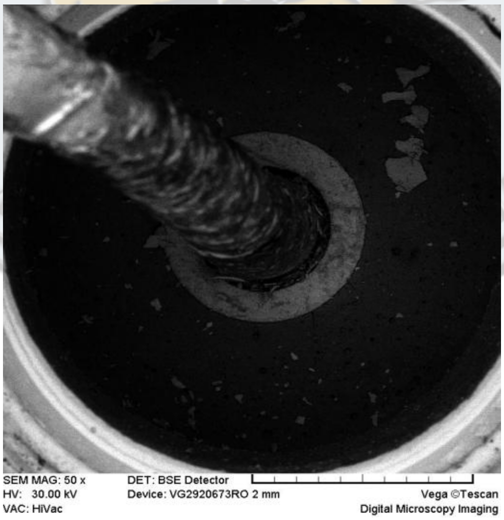

Fig. 9. SEM micrography of the case terminal at 1000 cycles.

Figure 9 illustrates the influence of the thermal cycling on the capsule's terminal. A pronounced corrosion of the copper terminal can be observed. This phenomenon recommends the use of a different metal or of an alloy which has a higher reliability with temperature.

5. Conclusions

A high temperature automating testing system for semiconductor devices was realized and tested. The electrical and temperature measurements demonstrated the system functionality. The system ability to create high temperature conditions (40-450 °C) allowed for testing devices on SiC, a semiconductor elevated temperatures. A custom software application was developed in TestPoint which executes the I-V characteristic of the DUTs.

The main advantage of this system is the high degree of automation and flexibility. These features make it suitable for thermal cycling tests, which need long time and large number of measurements for statistical data processing.

With this system we did preliminary thermal stress investigation on glass-metal packages that will be used for a temperature SiC sensor encapsulation. The thermal cycling performed in the these tests consisted of temperature variation from 50 °C to 400 °C and from 300 °C to 400 °C, respectively.

The presented experimental results demonstrate that the case is a good choice for the mentioned temperature range. The thermal cycling tests did not influence significantly the package leakage currents and did not degrade the package sealing glass. An evident corrosion of the copper terminal of the case has been revealed.

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REFERENCES

[1] B. Jayant Baliga, *Fundamentals of Power Semiconductor Devices*, Springer Science, **2008**.

[2] G. Brezeanu, F. Draghici, F. Craciunoiu, C. Boianceanu, F. Bernea, F. Udrea, D. Puscasu, I. Rusu, *4H-SiC Schottky Diodes for Temperature Sensing Applications in Harsh Environments*, Materials Science Forum, Vols. 679-680, pp. 575-578, **2011**.

[3] Bogdan Ofrim, Gheorghe Brezeanu, *Gas Sensors Based on Silicon Carbide MOS Capacitor*, Annals of the Academy of Romanian Scientists, Series on Science and Technology of Information, Vol. 48, No. 1, pp. 59-74, **2011.**

[4] Hewlett-Packard, *4140B pA METER/DC VOLTAGE SOURCE Operation and Service Manual*, April **1987**.

[5] DATAQ Instruments, *DI-158 Series User's Manual*, Revision L, **2010**.

[6] Capital Equipment Corporation, *TestPoint Reference*, 7th edition.

[7] Capital Equipment Corporation, *TestPoint Techniques*, 7th edition.

[8] www.keithley.com, *Low Level Measurements Handbook*, 6th edition.