COMPUTER CONTROLLED SETUP FOR PRECISE ELECTRICAL MEASUREMENTS – A STEP TOWARDS THE VIRTUAL INSTRUMENTATION

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Virtual instrument for low current and low noise DC electrical measurement based on Keithley 617 electrometer is developed. The software consists of two parts operating in parallel threads – GUI accepting the commands from the operator and a cycle for the data acquisition and control. The device is tested by measurement of resistor with high value of 100 GΩ. Taking the linear regression of the measured data it was found that the value of the conductance obtained is $1.29(\pm 0.001)x10^{-11}\Omega^{-1}$, which gives a resistance of 77.6 GΩ.. The intercept of $6x10^{-16}$ A obtained also from the linear regression demonstrates the low offset current of the device and the low leakage current in the whole measuring circuits.

Keywords: low current electrical measurements, virtual instrument, data acquisition and control

1. INTRODUCTION

Measurement of injection currents gives a valuable information about the electronic properties of the materials especially for wide-gap semiconductors and insulators [1]. At low voltages current of about $1x10^{-14}$ is flowing trough the sample but increasing 6-7 orders of magnitude, when conditions for charge carrier injection from the electrodes occur [2]. It is proved that the trap concentration and their distribution in energy could be extracted from the shape of the current-voltage (*I-V*) characteristic [3, 4].

Measurement of low current in high impedance samples could not be implemented with conventional digital multimeters. For low-level signals, more sensitive instruments such as electrometers, picoammeters, and nanovoltmeters must be used [5]. A typical example of such device is the electrometer Keithley 617. Moreover some special precautions should be taken to prevent the noise and the influence of parasitic signals generated from sources with piesoelectrical, triboelectrical or electrochemical origin.

When measuring high resistive samples the time-constant plays also an important role. For example, a shunt capacitance of 100 pF (including the input cable) and a source resistance of 20 GΩ results in a RC time constant of two seconds. Ten seconds must be allowed for the measurement to settle to within 1% of the final value [6]. The long time measurement could be automated by a virtual instrument.

A virtual instrument consists of an industry-standard computer or workstation equipped with powerful application software, cost-effective hardware such as plug-in boards, and driver software, which together perform the functions of traditional instruments [7]. With virtual instruments, engineers and scientists build measurement and automation systems that suit their needs exactly (user-defined) instead of being limited by traditional fixed-function instruments (vendor-defined).

This work aimed to accomplish a virtual instrument for low current and low noise electrical measurements based on electrometer Keithley 617.

2. Device Design

2.1. Hardware description

Block diagram of the computer controlled measurement system is presented on Fig. 1. It consists of vacuum chamber (1), electrometer (7) Keithley 617 and computer (9). The chamber is connected via flange (2) to the vacuum system based on an oil diffusion pump with a capability to maintain vacuum of $1x10^{-5}$ Torr.

A picture of the chamber (1) for the electrical measurement build form standard vacuum elements produced by Leybold is presented in Fig. 2. It provides a low current and low noise measurement and capabilities for a temperature control. Measured sample (a) is attached to the Peltier element (b) by silver or vacuum paste for a good thermal contact. Brass cooling block (c) and the corresponding copper tubes (d) are used to ensure the proper work of the Peltier element. Additionally the copper tubes serve as a holder for the cooling block, Peltier element and the sample. Especially designed flange for the electrical connections (e) is made from teflon, thus providing a good electrical insulation of the chamber. Brass pins laid on the teflon insulator are designed for current up to 5 A supplying the Peltier element or a resistive heater used for the temperature control. Copper wires are precisely solded to the pins for a good electrical contact keeping low noise

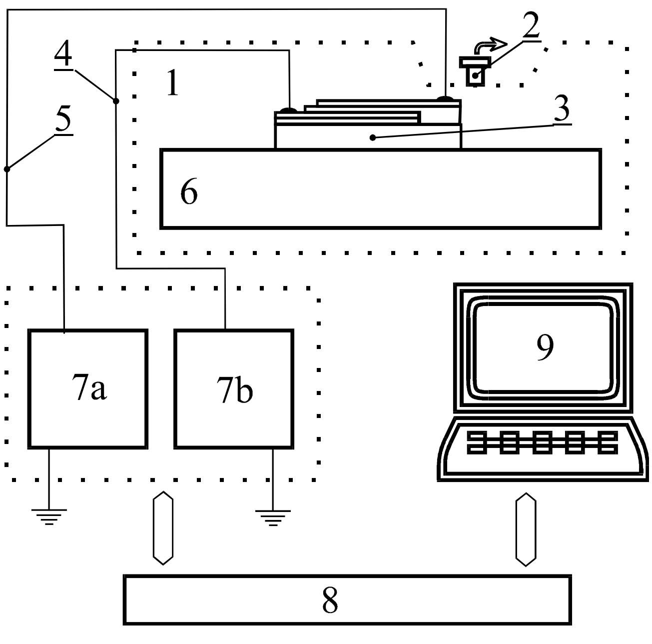

Fig. 1. Block diagram of the measurement system: 1 – vacuum chamber, 2 – outlet to the vacuum pump, 3 – sample, 4 – triple coaxial cable for low current measurements, 5 – BNC coaxial cable for voltage supply, 6 – sample holder with a possibility of temperature control, 7 – Keithley 617, (a) – voltage source, (b) – electrometer, 8 – GPIB interface, 9 – computer with extended GPIB card.

for the low current electrical measurements.

Voltage is supplied to the sample (Fig. 1. - (3)) by a standard BNC cable. Current is measured by the electrometer (Fig. 1. - (7)), connected trough a special triple cable provided by Keithley Instruments. The cable implements the requirements of low noise, low leakage current flowing trough the insulation and low parasitic voltages generated in the circuit. Programmable voltage source (Fig. 1. - (7a)) of the electrometer has 12 bits digital-to-analog converter, providing voltage conversion in the range of ± 102.35 V with a resolution of 50 mV. Electrometer part (Fig. 1. - (7b)) purses capability of precise and wide range voltage, current, resistance and charge measurement converting measured value by 14 bits ADC and displaying on 4½ digits display. Current is measured in the range of $1x10^{-16}$ – $1x10^{-2}$ A in 11 ranges with resolution of 100 aA and error less than 1.6%+66 counts for the most sensitive range of 2 pA. For the other ranges the error decrease reaching 0.15%+1 count for the less sensitive range of 20 mA.

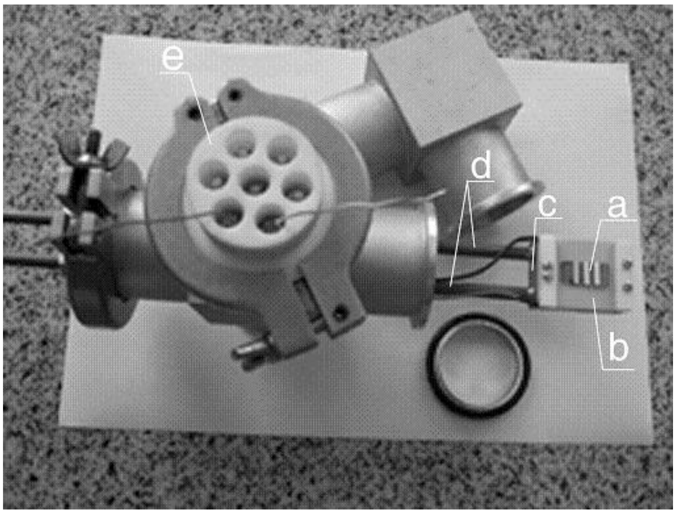

Fig. 2. Picture of the measuring chamber: a) – sample, b) – Peltier element for temperature control, c) – cooling block for the Peltier element, d) – tubes for cooling water supply, e) – teflon flange providing electrical connections.

GPIB communications follow the IEEE 488.2 standard. All three types of devices available on the interface are implemented – controller, talker and listener. Controller (Fig. 1. – (8, 9)) is built on PC computer with a GPIB PCI 3488 extended card manufactured by Adlink. The vendor provides drivers for the majority of programming media including LabVieW, LabWindow and VISA. The card is connected to the computer via 32 bits 3.3 or 5 V PCI bus allowing data transfer rate up to 1.5 MB/s, recording the data in the 1 KB FIFO read/write internal memory. Electrometer Keithley 617 implements both listen and talk functions. In the first case of listener it receives both commands from the controller and the value of the voltage to be applied on the sample. In case of talker it delivers the value of the measured current to the computer.

2.2. Software description

Software of the virtual instrument is created in C++ language. The driver for the communication with the hardware and the block for the measurements as well are developed using the reach capabilities of the C++ language including object-oriented programming. The panel of the virtual instrument is developed using the capabilities of the WinAPI libraries for creating buttons, controls and fields. The timing is developed on the base on the standard Windows timers, called from the C++ code. The usage of the GUI interface from one side and the data acquisition and control in real time from the other requires the software to operate in a multithreading mode. This is implemented calling standard WinAPI multithreading functions. A flow chart of the program is presented in Fig. 3.

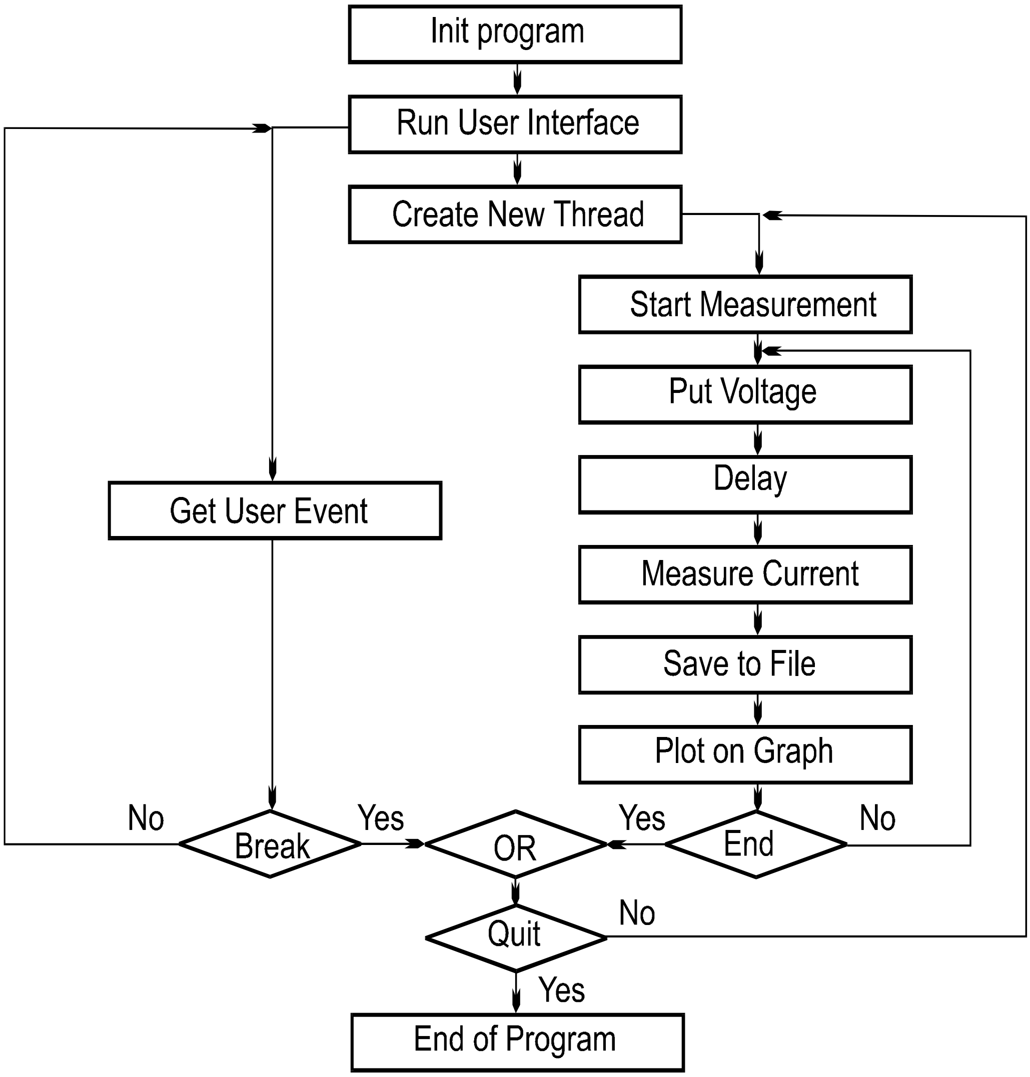

Fig. 3. Program flow chart.

After the initialization the GUI runs waiting in a dialog mode for operator's command and a second thread is created. The measurement flows in the second thread following the steps. Applying the voltage is implemented after switching the electrometer in listen mode and activation of the voltage source part. The delay time is necessary to avoid the capacitance current, which gives in our case no information about the properties of the material under study. After waiting of time larger than the time-constant of the measured circuit the DC current flowing trough the sample is measured. Finally the data are saved in a file and plotted in graph. After this procedure a new value of the voltage is applied on the sample and the cycle is repeated until the last point is measured. Meanwhile the GUI is running in the main thread catching user generated events for breaking the measurement.

3. TESTING AND MEASUREMENTS

The proper work of the system for computer controlled low current and low noise electrical measurements is tested by taking *I-V* characteristic of a resistor with a known value of 100 GΩ. The measured results are presented in Fig. 4. Low voltage range of ± 0.5 V is chosen to check the influence of the noise and potential non-linearity, which could be generated by the measurement circuit. The result obtained show that the *I-V* characteristic is symmetrical in both direction of the voltage scale, which exclude an influence of bad contacts or other sources of nonlinearities with piesoelectrical, triboelectrical or electrochemical origin. The measured points could be well approximated with straight line corresponding to the behavior of an active resistor.

The experimental error resulted from the noise of the measurement could also be determined from the parameters of the linear regression. The calculated in this way slope (conductance) and the corresponding error is $1.29(\pm 0.001)\text{x}10^{-11}\Omega^{-1}$, which gives a resistance of 77.6 GΩ. This is a satisfactory agreement with the value, denoted on the resistor. An intercept of $6\text{x}10^{-16}$ A obtained from the linear regression demonstrates also the accuracy of the measurement.

4. CONCLUSION

Hardware of a virtual instrument for low current and low noise DC electrical measurement is accomplished consisting of especially designed low noise measuring vacuum chamber, electrometer Keithley 617, GPIB interface based on Adlink PCI 3488 controller and computer.

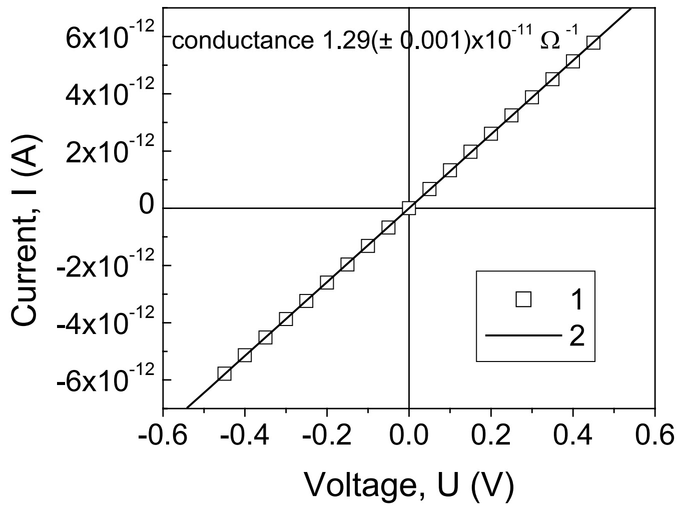

Fig. 4. *I-V* characteristic of a resostor with a known value of 100 GΩ: 1 – measrued points, 2 – linear regression of the measrued data.

The software of the virtual instrument consists of two parallel threads – GUI accepting the commands from the operator and a cycle for data acquisition and control.

The virtual instrument is tested by measurement of a resistor with high value of 100 GΩ. Taking the linear regression of the measured data it was found that the value of the conductance obtained is $1.29(\pm 0.001)\text{x}10^{-11}\Omega^{-1}$, which gives a resistance of 77.6 GΩ for the measured sample. The difference corresponds to an error of 2.2 dB which satisfy the requirements for measurement of high value resistors. The intercept of $6x10^{-16}$ A obtained also from the linear regression demonstrates the low offset current of the device and the low leakage current in the measuring circuits.

5. Copyrights

Know-how and detail schematics of the measuring chamber, presented in Fig. 2. is owned by Centre for Innovative Development – Ltd.

6. Acknowledgments

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