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A USB PROBE FOR RESISTIVITY VERSUS TEMPERATURE AND HALL COEFFICIENT

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1. ***Abstract***

Computer on line measurements offer new opportunity in teaching/learning physics. One of them is to reduce the gap between physics research methods and experimental works in schools. In the last years Udine Physics Education Research Unit (PER-U) address research in preparing innovative learning packages for secondary school to offer experience of research methods (TRR, RBS, cross section, ...) in school lab activities. The experimental study of resistivity versus temperature combined with Hall effect coefficient measurements give the opportunity to obtain information on electrical transport properties in solids. Up to now this measurements are mainly carried out at room temperature. The resistivity is one of the simplest experiments in basic physics and the Hall coefficient measure is rarely measured and with a not easy to set group of instruments in advanced course. In the framework of Mosem EU project on superconductivity, we develop a USB probe for the measurement of resistivity versus temperature in metal, superconductor and semiconductor solids and a combined room temperature Hall coefficient measurement for metals and semiconductors. The resistivity measure can be carried out in the 78-400K temperature range selecting different controlling heating rate. Current and magnetic field are parameters to selected by the user in Hall coefficient measurement. The software interface is designed to be user friendly, giving to the user the opportunity to set up the relevant parameters of the measurements and to have a direct vision of the real time graph during the experiments. High quality measurements give to opportunity to fit data with curves based on theoretical models.

2. Introduction

The system to measure the resistivity versus temperature has been designed so as to implement measures in a four-terminal configuration, the two external contacts are used for the injection current and the two internals to measure the voltage, proportional to the electrical resistance of the sample.
Measurement procedure can be chosen by the user:

- ✓ thermal inertia, from the temperature of nitrogen liquid at room temperature
- ✓ ramp with continuous heating
- ✓ temperature of thermal inversion. Is chosen, via software, the gap in temperature between a measure and the next.

Each measurement is made by detecting the voltage, on the two internal contacts, first time with the injected current and then subtracting the voltage corresponding to zero current.
Under these conditions it is obvious that there is no need for manual adjustment of the offset because the correct measure of the voltage will be that obtained from the difference of the two readings (measure “quasi ac”).

3. The system

To make the resistivity measurements have been designed in three hardware modules:
1. constant current source;
2. voltage measurement;
3. heater.

Figure 1 shows the interface card for connection (via USB) to your computer.

Fig. 1 - Interface card

The ***generating current circuit***
This current can be varied from 1 to 150 mA through VREF1 tension generated by software.
The current value remains strictly constant during a change of resistance of the sample.

The ***reading circuit*** of the input voltage. The potential difference between the two internal contacts is obviously proportional to the electrical resistance of the sample and is withdrawn into the operational amplifier AD627, electrically powered with dual VCC (+10 V) and VEE (-10V), as it provides the ability to measure positive and negative tensions.
The card includes 6 (six) different circuits of reading (use one at a time) the voltage on the two internal terminals on the sample, each with its own gain to handle the broadest range of measures without the need for manual adjustment.

The ***module of the heater*** can provide a maximum current of 250 mA, directly accessible from the USB port of your computer. For stronger heating it is necessary to use a small external power supply.
The command for the injection of the heating current is run by software based on the measurement procedure chosen.

To ***measure the temperature*** is used as sensor a PT100 platinum resistance (R = 100 ohms at 0 ° C), with a variation of 0.4 ohm per ° C. This allows, with a 12-bit analog converter, to obtain, in the temperature range that interests us, a sensitivity of 0.05 ° C.
Measures of temperature and resistivity are decoded with two 12-bit analog-digital and multiplexed by a PIC 18F6527 microcontroller from Microchip Technology programmed for the purpose required.
The data is sent to the computer through a USB connection, achieved through the use of decoding module FT245BM.

4. Measurement of resistance

4.1 Superconductors

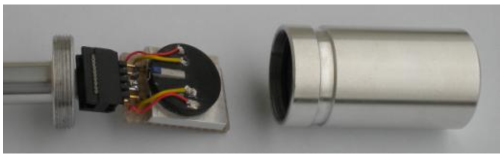

Fig. 2 – YBCO sample with aluminium container.

For measurement we used a YBCO (Yttrium Barium Copper Oxide) "Colorado." On the contacts side we have glued the temperature sensor, on the other side we have positioned the heater, made of an aluminium plate of thickness 4 mm, inside of which are housing two 10 ohm resistors in series (heating current of 220 mA, taken directly from the USB connection).
Everything was placed inside a aluminium container, closed at the top with a screw cap, used for immersion in liquid nitrogen. The top of the container is made with a tube, suitable for the passage of the cable connection and size that do not seal the container.

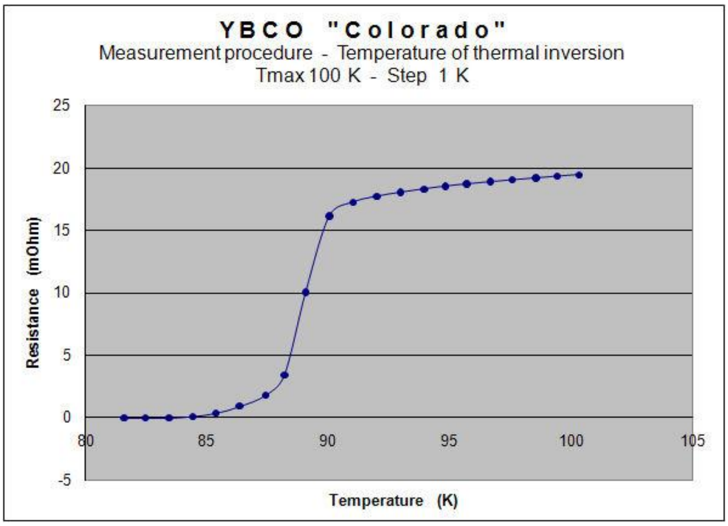

Fig. 3 - Example of measurement.
The duration of measure is about 15 minutes

4.2 Semiconductors

Even in this case the heater is formed by a plate of aluminum of dimensions 22 x 22 x 4 mm, within which are housed four 1.2 ohm resistors connected in series to provide a total value of 4.8 ohm (Fig. 4).

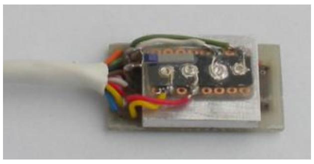

Fig. 4 - Semiconductor sample.

The power supply for the heater is given by a small external power supply (typical power adapter to charge cell phone or similar) from 5 V to provide a suitable heat output of 5 watts, required to bring the sample from nitrogen liquid temperature to 400 ° K .

The sample of semiconductor has been packaged as in the previous case and everything was placed inside a aluminium container (the bottom of the container used for superconductors) partially immersed in nitrogen liquid for cooling. Once at the desired temperature, the container is extracted from the nitrogen liquid, maintained in the environment of the Dewar, and begin continuous heating. In Figure 5 we see that in a first zone behavior resembles that of metals and the second part of the curve the concentration of free carriers increases exponentially with increasing temperatures.

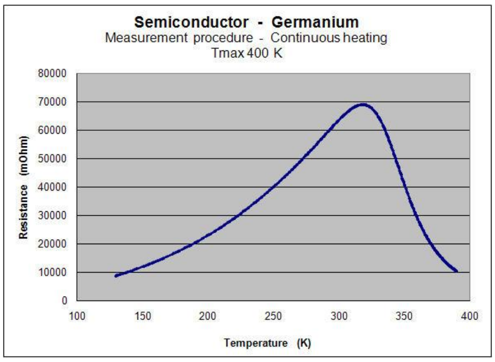

Fig. 5 - Example of measurement.

4.3 Metals

The sample is made with a piece of insulated copper wire wrapped as shown.

The measurement procedure is the same already described for semiconductors.

Sample data reported here (Fig. 6b) with the relative fitting are rapresentative of the sensitivity and reability of the system.

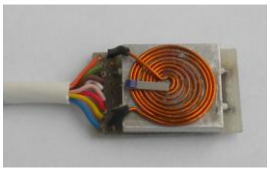

Fig. 6a - Copper sample.

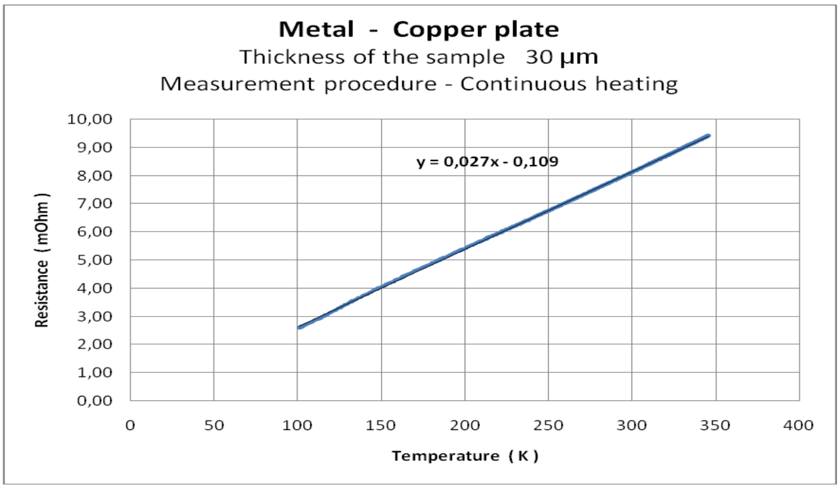

Fig. 6b – Resistance measurements and fitting

4. Software

The software interface for the measurement of resistivity is quite simple and only takes a few tricks to its proper use.

You first need to select the channel associated with the measure (Fig. 7a). This is done according to the value of the resistance of the sample and the injected current, so as not to bring the operational amplifier saturation.

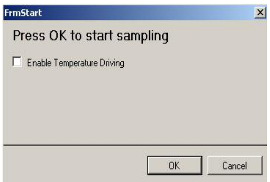

Fig. 7b – Software

Once you press the button "Start" the system asks if you want to continue with the simple measure, without heating, or if you want to

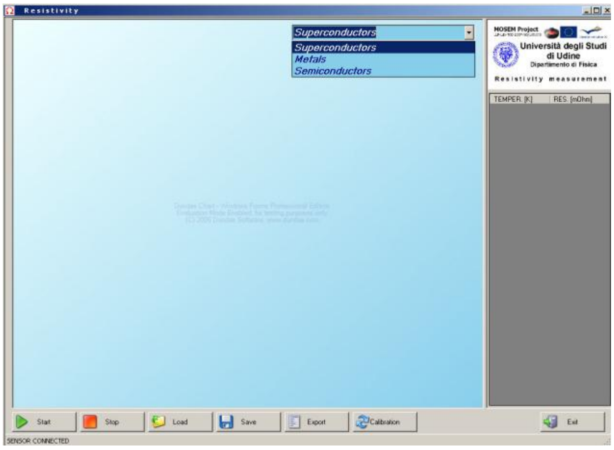

Fig. 7a – Resistance measurement Software set the heating controls. To measure free, just press "OK" (Fig. 7b).

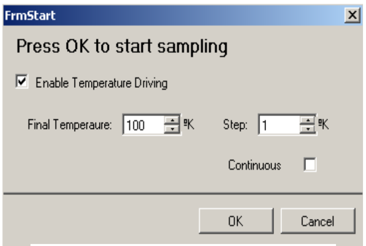

Fig. 7c – Software

To make the measurement with the heating is required to tick the corresponding application.
The screen that appears as a consequence of this choice, you can set the value of the maximum temperature at which it wants to bring the sample (starting from the current temperature), the step that will be used in temperature controlled by heating or set the continuous heating (Fig. 7c).

6. Hall effect measurement

The Hall effect measurement system is managed with a very simple software, suitable for both samples metals and semiconductors (Fig. 8a).

Fig. 8a – Hall effect measurement Software

Another opportunity is to be able to review the law of variation of the magnetic field of permanent magnet system used for measurement, depending on the distance between them (Induction magnet control).

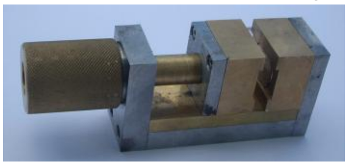

Fig. 9 – Magnet system.

In the Fig. 9 shows the permanent magnet system used to measure Hall effect for the metal and semiconductor samples.
To measure Hall effect on semiconductor and metal samples, it works simply by choosing the desired option on the menu to scroll up on the right of the screen.
After choosing the option to measure, the first thing to do is that of calibration. You start this process by taking on the "Calibration", with the sample completely outside the magnetic field. This screen shows the window like in Fig. 8b, showing the voltage measured on the active channel.
It acts on this multi-turn potentiometer on the sample in order to read a potential equal to 0 (zero).

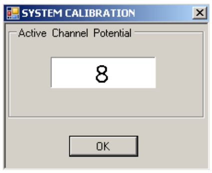

Fig. 8b – Software

This procedure is necessary to eliminate the potential difference that inevitably is created for the not perfect alignment of the terminals for the measure of the d.d.p. Hall.

Fig. 8c – Software

After finishing this procedure begins by acting on the measure button "Start".
The system asks you to set the initial value of current injected into the sample, the final value and the step current you want (Fig. 8c).
At this point the measurement can be performed automatically or step by step at the request of the operator. To do this you must tick the appropriate option.
Depending on the type of sample chosen for measurement, metals or semiconductors, vary the range of current accepted. For metallic samples is requested the same external power supply used for heating in the measurement of resistivity.

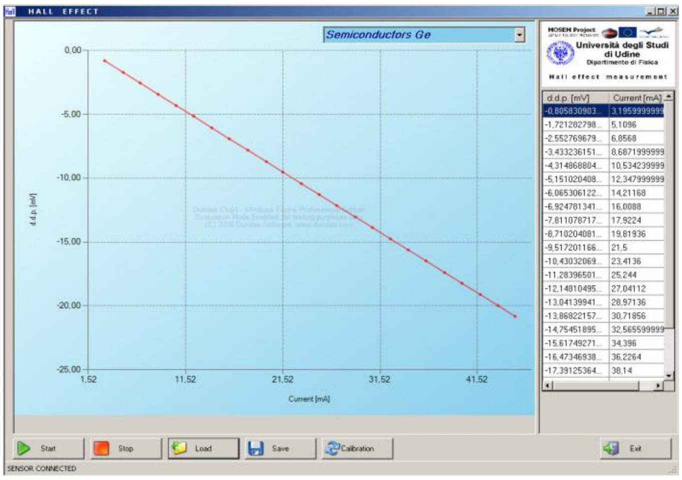

Fig. 10 - Measurement on a sample of germanium doped

7. Address reference

For information about the availability of the system described in this paper (hardware and software) contact: mario.gervasio@uniud.it or marisa.michelini@uniud.it

8. References

Michelini M, L'elaboratore nel laboratorio didattico di fisica: nuove opportunità per l'apprendimento, Giornale di Fisica, XXXIII, 4, 1992, p.269

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