Programmable relay board for van der Pauw method

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1 Introduction

Sheet resistance is a very important property of a material. If the sheet resistance and thickness of a material are known, we can easily calculate the resistivity and electrical conductivity. If the conductivity of an object is known, we will be able to tell how well that material allows the current flow. Also, from the resistivity, we can determine whether the sample is exceeding when it comes to its structure and whether it would make sense to measure it in low temperatures. If the resistivity of a sample is high, we know that it would not be beneficial to measure it, because that sample is not superconducting.
One of the methods how to determine the sheet resistance of a very thin sample is the van der Pauw method, which is described in detail below.

2 Van Der Pauw's method

Van Der Pauw's method requires two measurements of resistance in order to determine the sheet resistance of a sample. To measure the resistance of a complex-shaped sample, we need four small and competent contacts on its confines: throughout the two of them, we let the current circulate, while on the other two contacts, a voltage difference appears. As a result of that, we can evaluate the first needed resistivity (R_1). The second resistance (R_2) is measured similarly by altering the combination of contacts for the current and voltage paths.[1]
For example, let's say our sample is rectangle-shaped (although the van der Pauw method can be used on samples regardless of their shape), and it has four contact positions, which we marked as $1, 2, 3$ and 4, as shown in the figure 1.

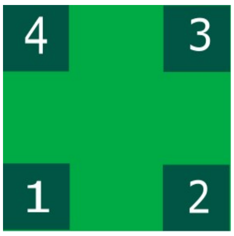

Figure 1: Positions of contacts on a rectangle-shaped sample

In this experiment, we chose to have four resistance measurement positions, depending on the wiring diagrams shown in figure 2.

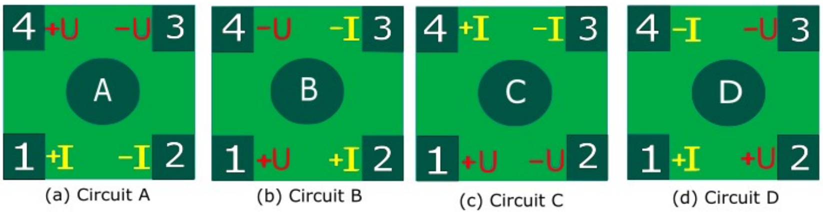

Figure 2: Wiring diagrams for Van Der Pauw method

We define the resistance $R_{12,34}$ as the potential difference $V_4 - V_3$ between the contacts 4 and 3 per unit current through the contacts 1 and 2.[2] The current enters the sample through contact 1 and leaves it through contact 2. Similarly, we can define $R_{23,41}, R_{43,21}, R_{14,32}$, where the first two numbers in notation mean at which points the current enters and exists, while the other two numbers represent the position of contacts in which voltage difference occurs.

To determine the sheet resistance, we use the van der Pauw formula below:

$$\exp\left(-\frac{\pi R_{12,34} d}{\rho}\right) + \exp\left(-\frac{\pi R_{23,41} d}{\rho}\right) = 1 \tag{1}$$

where d is the thickness of a sample, and ρ is the specific resistance.
Therefore, the sheet resistance is:

$$R_s = \frac{\rho}{d} \tag{2}$$

3 16-Channel 12V Relay Board

A relay board is a computer board consisting of a batch of relays. A relay is a device used to cut off or establish a circuit through an electromagnet which opens and closes current contacts. Typically, a single relay has 3 ports (contacts): common (usually labelled "C" or "COM"), normally open ("NO") and normally closed ("NC") port.

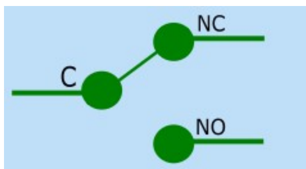

Figure 3: Single relay ports

The normally open port does not flow electric current when disconnected, whereas, the normally closed port flows the current when the switch is turned off.

In this project, we used a 16-channel relay board, with 12V supply voltage. The relays are controlled by a USB port, which is connected to the PC.
A relay board can be a very useful tool when it comes to minimizing the mechanical work with electric devices. For the van der Pauw method specifically, instead of manually connecting and disconnecting current/voltage cables between contact positions and manually setting current values, we tell the relay board exactly on which contact positions we want to measure current or voltage difference, and through programmed multimeter, we set the current values.
Essentially, it represents a small step towards automatization.

4 Experimental part

This scheme shows how the cables are connected between contact positions, current/voltage sources and relays throughout a relay board and a connector. The connector has two components: male and female. The male

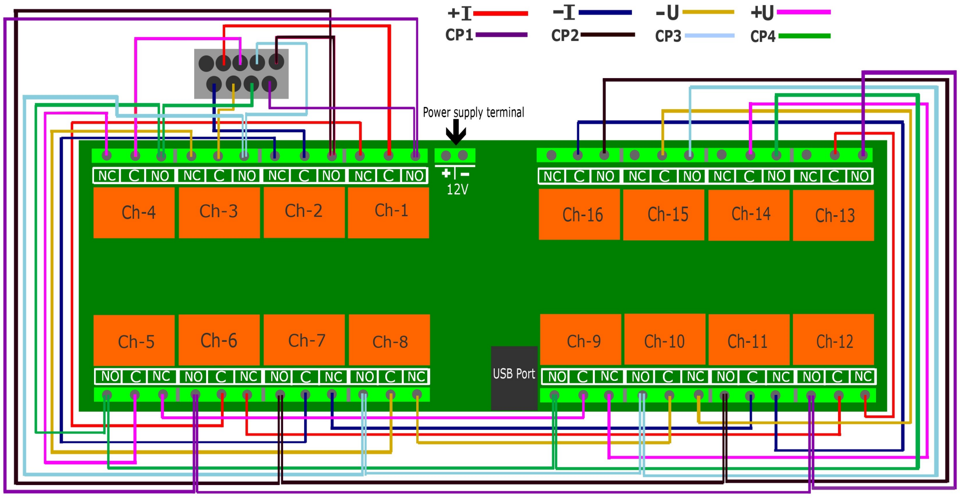

Figure 4: Schematic wiring diagram for a relay board
CP - contact position

connector was used for connection of the relay board, and female for contact positions and the current source, as shown in the figure 5.

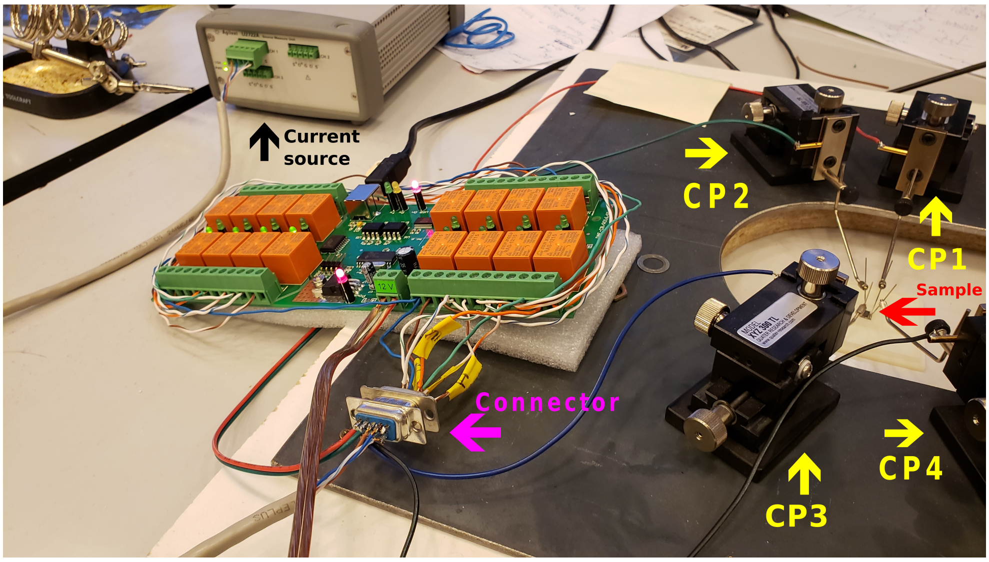

Figure 5: Wiring
CP - contact position

The black probes are manually movable and have very thin needles used to establish the contact with a sample, usually in the very corners of it.

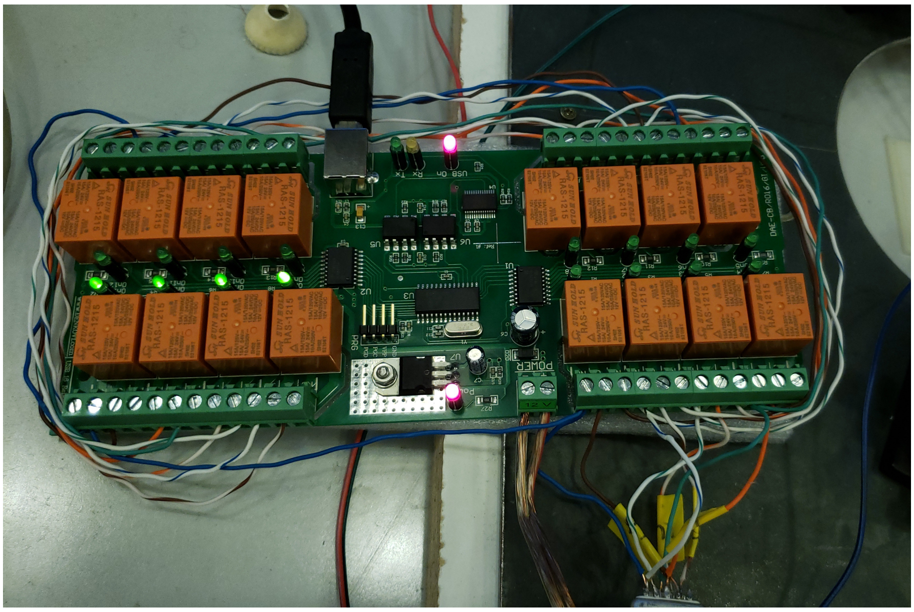

Figure 6: Relay board used for van der Pauw method

References

[1] Xiaokai Hu et al. "Electrostatic derivation for the van der Pauw formula and simulation using arbitrarily shaped resistive materials". In: *AIP Advances* 12.7 (2022), p. 075208. DOI: 10.1063/5.0081561. eprint: https://doi.org/10.1063/5.0081561. URL: https://doi.org/10.1063/5.0081561.

[2] L. J. van der Pauw. "A method of measuring specific resistivity and Hall effect of discs of arbitrary shape". In: *Philips Research Reports* 13.1 (1958), pp. 1–9. DOI: https://doi.org/10.1142/9789814503464_0017.