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A BRIEF STUDY OF METHODS TO DETERMINE THE ELECTRICAL RESISTIVITY OF MATERIALS

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ABSTRACT

Present study deals with the study of methods to calculate the resistivity of materials. Different methods are discussed which determine the resistivity of specific materials on the basis of their shapes and sizes. Their working, structure, advantages and loopholes are discussed in a brief manner. Materials are categorized according to their magnitude of resistivity. The two probe method is helpful in measuring the resistivity of high resistive samples while four probe methods can be used for materials with low resistance. Pulse probe method measures the resistivity of materials having small physical dimensions. The Montgomery method is useful in finding the individual resistivities of anisotropic materials.

Keywords: Electrical resistivity; Electrical probes; resistance; Pulse probe; anisotropic materials

INTRODUCTION

Materials behaviour is mainly based on the nature of their constituents. The physical and nonphysical features are then attributed to the components and vary by external factors such as pressure and temperature, in general. Specified electrical properties also depend upon the structure of the material. Due to that, conducting, with low resistivity, materials are used to supply electric current to long resistance. While in some cases materials with high resistivity are used in different appliances e.g. electric heater, iron filament, etc. Electrical and electronic systems use electrical resistance as the key parameter for the selection of materials. The right selection of material is based upon the required application. Power distribution systems depends on electrical resistivity to assess transmission lines, earth grounding, and soil material.

Electrical resistivity of a particular material can be calculated by using various methods and models. The shape of the material sample and contact resistance defines which method is suitable for precision measurements. The resistivity of high resistive samples can be measured by using two probes methods (ohm meter or voltmeter – ammeter measurements). Four probes methods can be used for the measurement of resistivity of materials those who have low resistance and single crystals. The resistivity of the pellets and bulky samples can be measured by using Montgomery, van der Pauw, and Smith techniques. These are conventional techniques by which resistivity can be measured but other techniques which use modern technology analyze the resistivity.

METHOD

This is the most used experimental setup for calculating resistivity. To be applicable the cross-sectional area of the material must be determined precisely. Then by measuring the resistance and dimensions of a specimen, the resistivity is calculated [1].

Working

In the procedure, the material is cut and transformed into the desired shape (rectangular shape). The material is connected to copper wires from both of its opposite sides. This technique is known as a two-point technique because the material is connected to wires at two points. A current source is used to provide an alternating current that is applied between two poles and the voltage resulted is measured. Ohmic contacts must be applied to the ends of the bar. Using two sharp probes, accurately spaced at distance (L) apart, the voltage drop between two points is measured. At lower frequencies, the capacitance is no longer affected by capacitance so at this stage resistivity is calculated by knowing the values of voltage and current applied across two electrodes. Then resistivity can be calculated by

$$\rho = VA / IL \tag{1}$$

where,

ρ = resistivity in ohm-cm, V = voltage between the two probes, A = cross-sectional area in square centimetres, I = current flowing through the rod inspires, L = spacing between the probes in centimeters

Advantage

This method is found to be very helpful when the resistance of a given sample is large and it is a refinement of the bulk resistance method because it allows the determination of changes of resistivity along the length of the bar.

Circuit for measurements

The tips of the probes are generally made of hard and brittle elements known as osmium or tungsten carbide. The two probes are arranged on separate arms at the end in such a way that each armrest on a kinematic system that completely eradicates side by side movement of the probe tips when they touch the material surface. The probe tips are arranged and positioned very close to each other with a very small distance of 20 μm. The probe tips are allowed to come in contact with the sample gently because of the reason that pressure is very high at small contact areas of probe tip sand is more than a million pounds per square inch[3]. The illustration of this method is shown below

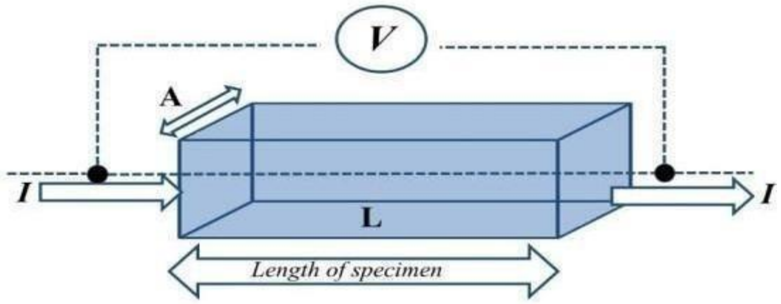

Figure 1. A two probe experimental setup[4].

Limitations

While experimental work, resistivity measurement with a two probe method does not give valid results due to the following reasons;

- The presence of small amounts of resistance between specimens and wires and apparatus used causes the addition of more resistance those results in higher resistivity than the actual one.
- Most occurring complications often arise during the experimental process. When the current has applied the resistivity of the given material is modulated which causes the difference in the results. These types of problems mostly occur in semiconductors.
- One issue that is the main reason for valid results is that contacts present between electrodes and samples (semiconductor) have different electrical properties. For this reason difference in resistivity, calculation occurs.

This is the reason why the four-probe method is used as it successfully eliminates these problems[1].

Measurement of Resistance of a sheet

The resistivity of materials having thin films or sheets can be calculated by this method. The material whose resistivity is to be determined is cut into rectangular or square shapes with equal length and width. Then resistivity in this method is measured by the given formula

$$\rho = Vwh / Il \quad (2)$$

here, ρ = resistivity in ohm-m, V = Voltage measured (volts), w = Width of the sample (m), h = Thickness (m), I = Current in amperes, l = Length of the film (m). A square film where the width becomes equal to length than the above resistivity equation becomes [5].

$$\rho_{\text{(of square film)}} = V \times h / I \quad (3)$$

The “sheet resistivity” of the material which is the resistivity of a material's square film is expressed by the symbol ρ_s. The “sheet resistance” R_s is given by [1].

$$R_{s \text{ of square film}} = VI \quad (4)$$

This method is commonly used to determine the resistance of films having random and deformed shapes and sizes. Thus, to conclude we can say that sheet resistance does not depend upon the size of the square or thickness of sheet[5].

FOUR PROBE METHOD

This method is the standard & frequently used for measurement of resistivity of semiconductors accurately. One feature for which it is highly appreciated in the lab work is that it can determine resistivities of both bulk and thin-film materials and their expressions are written differently [2].

Advantages

Its main advantages are;

- It overcomes the problem of contact resistance
- The issue arises in two probe methods for different electrical properties of contacts present between electrodes and samples (semiconductor) that causes resistivity differences are overcome by four-probe methods.

- The resistivity of materials having various shapes and sizes can be accurately measured by this method
- Resistivity measured by this method has a wide range (micro ohm to megaohm).

Working and Structure

The contact of the four points is made with the probe and the substance to measure the resistivity of the material. Current is applied which passes through two outer probes and between the two inner probes the voltage is measured in volts. Hence resistance is calculated by this process.

In its structure, four tungsten metal tips are arranged in such a way that they are equally spaced. The spacing between probes should be at least ~ 1 mm. During the probing of material, these tips are supported by springs so that damage of the sample can be minimized. Resistivity (ρ) in this case is given by

$$\rho = V_{D \times A / DI} \quad (5)$$

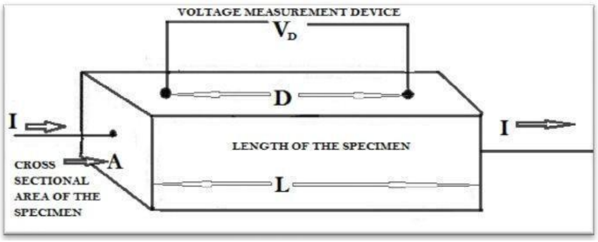

Figure 2. Illustration of Four probe technique. Picture adapted from [2].

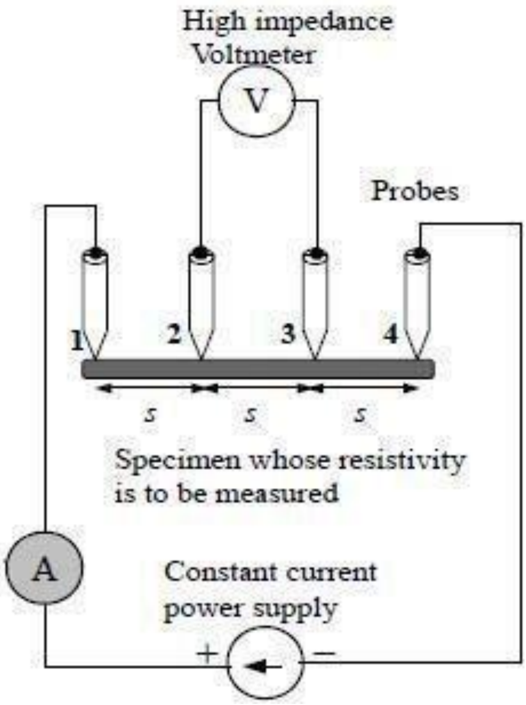

Figure 3. Circuit for Resistivity measurement [2].

Necessary Assumptions

Some necessary assumptions are made to measure resistivity by this method. These are;

- The material's resistivity in the area of measurement is constant.
- The surface at which the probes arresting must be flat, smooth and vibrationless.
- The four probes contact the surface in a straight line and their spacing can be accurately controlled.
- The diameter of the contact between the probes and the samplemust be small as compared to the distance between probes.
- When any of the above conditions are not fully met, error in the measurement results.

PULSE PROBE METHOD

C.R.B Lister first developed this method and it is also known as the modified DC method. After some modifications, this method becomes perfect to determine the resistivity of the material.

Working

The working of this method is very simple. A high voltage is applied to the material in short pulses. and on the other hand, the fast oscilloscope or amplifiers are used to measure the current across pair of probes. The duration of the pulse is very short and is repeated a few times. or this reason, the density of the current is very high during these pulses of high voltage is very high which does not cause overheating of the sample[2].

Advantage

The resistivity of the materials which have very small physical dimensions and joule heating problems is only measured by this method. A block diagram of the Pulse probe is given below

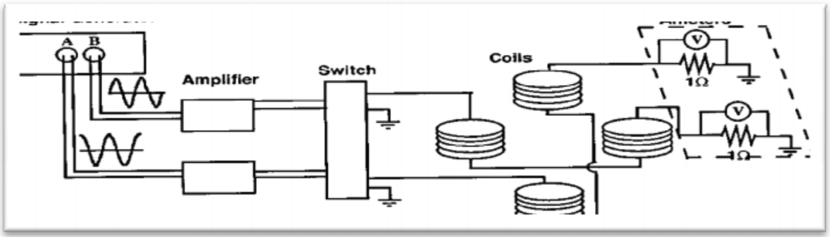

Figure 4. Schematic illustration of the pulse probe adapted from [2].

MONTGOMERY METHOD

This method was devised from the experimental setup of van der Pauw by Montgomery. By this method, the individual resistivities of anisotropic materials can be determined[6].

Working

In this method, the contacts are used and are applied on the corner of anisotropic sample. Then current is applied whose direction is parallel and after this, the voltage is measured in volts in the pair of contacts that are situated in the opposite parallel direction. For a single specimen, it is cut into a rectangular shape with orthogonal faces according to the principle of crystallographic axes.

Current is directed by the help of contacts on two end corners of the specimen face and the voltage is measured by the contacts that are located on other end corners of the opposite side of the specimen face.The specimen is rotated by an angle of 90° and similar measurements are taken. It is shown in the given figure. By doing this separate two tensors terms of electrical resistivity are determined. To calculate the third tensor component of the resistivity the material is rotated again by some angle the measurements are taken.

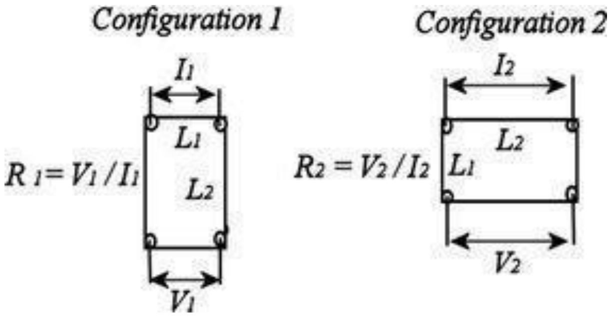

Figure 5. Different configurations of anisotropic material[6].

Advantage of the Montgomery method

Other methods have a short circuit and have permanently arranged electrodes along some perimeter which makes it impossible to determine resistivity in different directions at the same time. To overcome this problem the Montgomery method is developed and used to measure the resistivity of an anisotropic material at the same time. One great feature of this method is that it tells whether the sample is isotropic or anisotropic by defining dimensions.

Limitations

- To get valid results by Montgomery method the specimen must have a square or rectangular shape and its thickness and width must be constant because the voltage has a nonlinear relationship with thickness
- The Montgomery method is very sensitive to the path of the current chosen.

Determination of pellet resistivity by Montgomery Method

Pellet is obtained by pressing the powder and transforming it into circular discs. Four-pint contacts are made with the pellet of constant thickness. This contact is made around the pellet surface in rectangular form ABCD. "b" is a distance between contacts A and B while 'a' is the distance between B. The pellet's thickness should be less or equal to 0.3 $\sqrt{ab}$

Experimental setup of a Montgomery method is given below

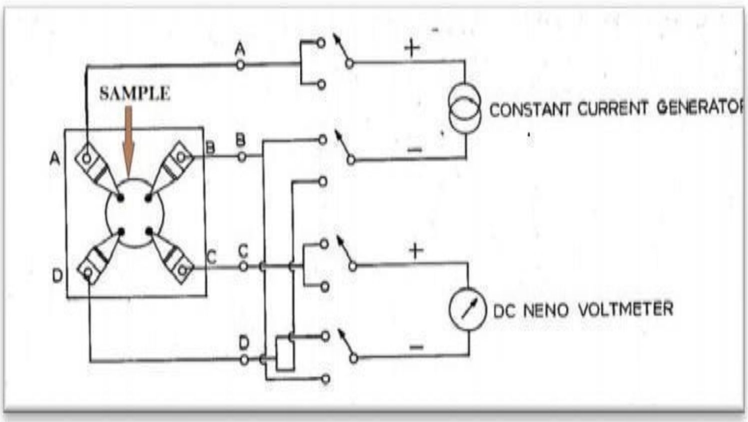

Figure 6. Resistivity measurement of pellet by Montgomery method[6].

In this method, two resistances are measured. For R1, the current is applied between AB, and voltage is measured across CD. For the second resistance R2, the current is directed through AD, and voltage is determined in volts across BC. Then the current is varied by changing its direction so that the R1 and R2 can be measured. The resistivity according to the theory of Montgomery is given by formula

$$\rho = HER \qquad (6)$$

Where, H = It is a geometric parameter which is a function of the ratio of width and length, E = thickness of the specimen, R = the ratio of the voltage between the two contacts on to the current between the opposite two contacts[6].

CONCLUSION

The Present article has briefly discussed the methods to calculate the resistivity of materials. They determine the resistivity of specific materials on the basis of their shapes and sizes. Their working, structure, advantages and loopholes are discussed in a brief explanation. It shows that materials are classified according to their magnitude of their resistivity. So the two probe method is helpful in measuring the resistivity of high resistive samples while four probe methods can be used for materials with low resistance. Pulse probe method measures the resistivity of materials having small physical dimensions. In the same manner, the Montgomery method is useful in finding the individual resistivities of anisotropic materials.

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