DEPARTMENT OF PHYSICS AND NANOTECHNOLOGY
SRM INSTITUTE OF SCIENCE AND TECHNOLOGY

18PYB103J –Semiconductor Physics

Module-IV Lecture-2

Four-point probe technique-linear method **&** Van der Pauw method

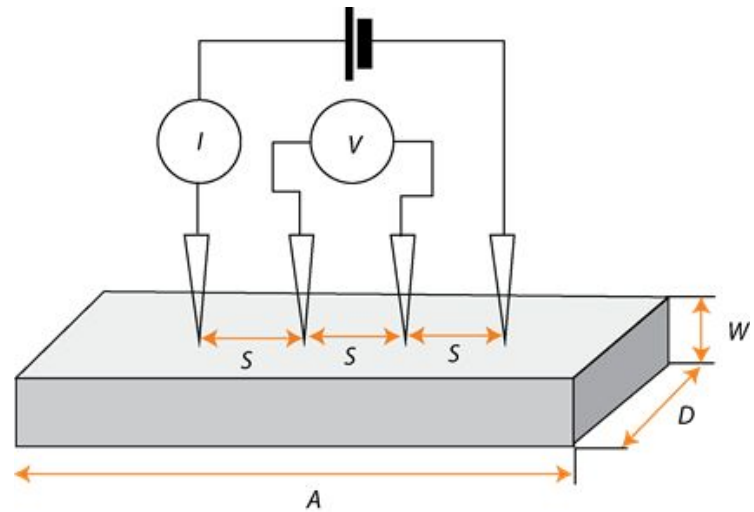
Four-probe method:

This method provides the measurement of the resistivity of the specimen having the wide variety of shapes but with uniform cross-section.

The soldering contacts proposed in two-probe method are replaced by pressure contacts to eliminate the last two problems summarized above.

In this method, four probes are utilized to measure the resistance of the samples. For example, two of the outer probes are used to send the current from the source meter and other two inner probes are used to measure the voltage drop across the sample.

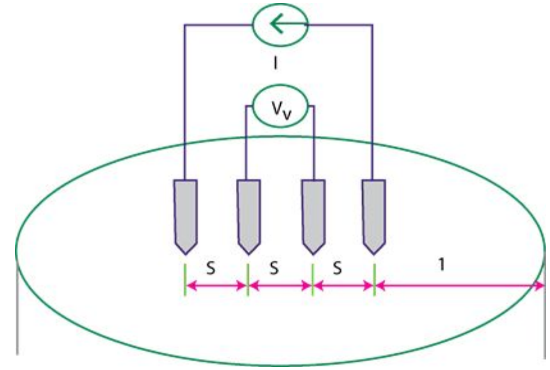
The typical set up of the four-probe method is shown in Figure. There are four equally spaced tungsten metal tips supported by springs at one end to mount the sample surface without any damage.



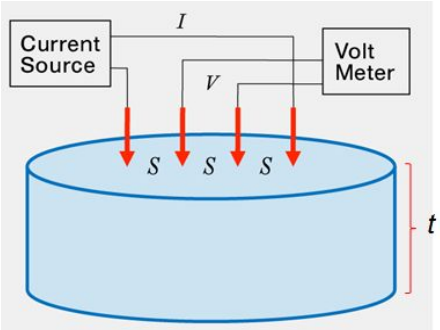
Two common techniques used in four-probe method are (i) Four-point collinear probe method and (ii) van der Pauw method.

A high impedance current source is used to supply current through the outer two probes, which sets up an electric field in the sample. The potential difference developed across the inner probes, which draw no current due to the high input impedance voltmeter in the circuit, is measured through two inner probes.

Four-point collinear probe method:
This is the most common way of measuring the resistivity of a material, which involves four equally spaced probes as shown in Figure, in contact with a materials of unknown resistance. This method can be used either in bulk or thin film specimen.



Schematic of four-point collinear probe method.



Schematic of four-point collinear probe method on bulk material.

Four-point collinear probe method: For Bulk:

Consider a bulk material as shown in Figure , where the thickness (t) of the materials is much higher than the space between the probes (s), then the differential resistance due to spherical protrusion of current emanating from the outer probe tips is

$$\Delta R = \rho\left(\frac{dx}{A}\right)$$

Carrying out the integration between the inner probe tips,

$$R = \int_{v1}^{v2} \rho \frac{dx}{2\pi x^2} = \int_{s}^{2s} \rho \frac{dx}{2\pi x^2}$$

$$R = \frac{\rho}{2\pi}\left(-\frac{1}{x}\right)\Big|_{s}^{2s} = \frac{\rho}{2\pi}\frac{1}{2s}$$

where probe spacing is uniform. Due to the superposition of current at outer tips, $R = V/(2I)$. Therefore,

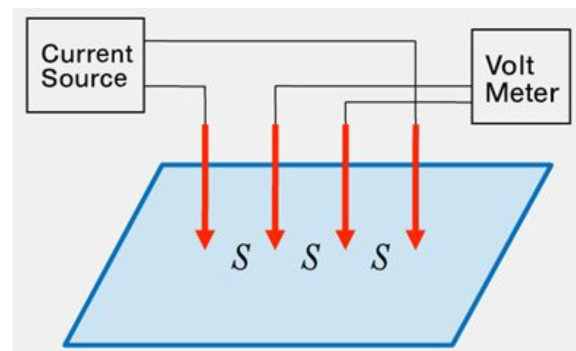
$$\rho = \left(\frac{V}{I}\right)(2\pi s)$$

Four-probe method: For Thin sheet:

For a very thin layer as shown in Figure, where the thickness of the sheet t << the space between the probes, s, we can get current rings instead of spheres. Therefore, the expression for the area is A = 2π$x.t$. Therefore, the derivation for resistance turns out to be:

$$R = \int_{v1}^{v2} \rho \frac{dx}{2\pi x t} = \int_{s}^{2s} \frac{\rho}{2\pi t} \frac{dx}{x}$$

$$R = \frac{\rho}{2\pi t} ln(x)|_{s}^{2s} = \frac{\rho}{2\pi t} ln2$$



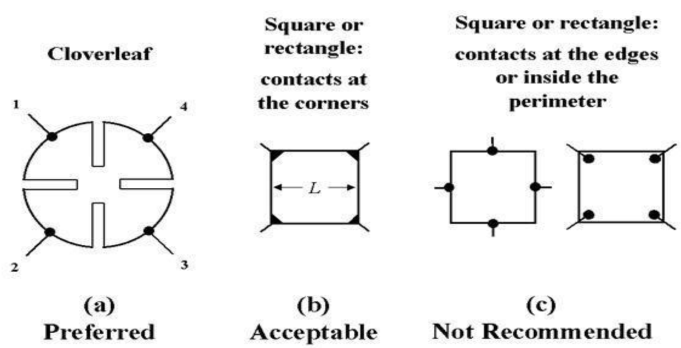
Schematic of four-point collinear probe method on thin sheet.

where probe spacing is uniform. Due to the superposition of current at outer tips, $R = V / (2I)$. Therefore,

$$\rho = \frac{Vt\pi}{I \ln 2}$$

van der Pauw method

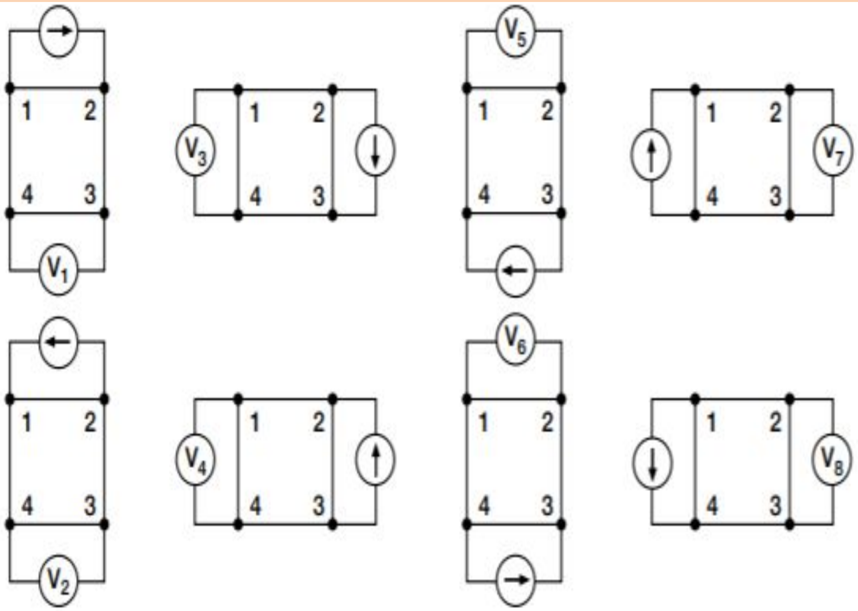
- The van der Pauw method is a technique commonly used to measure the resistivity and the Hall coefficient of a sample. There are five conditions that must be satisfied to use this technique:
- The sample must have a flat shape of uniform thickness. The sample must not have any isolated holes. The sample must be homogeneous and isotropic.
- All four contacts must be located at the edges of the sample. The area of contact of any individual contact should be at least an order of magnitude smaller than the area of the entire sample.
- In order to use the van der Pauw method, the sample thickness must be much less than the width and length of the sample. In order to reduce errors in the calculations, it is preferable that the sample be symmetrical. There must also be no isolated holes within the sample.



Make four ohmic contact with 8 periphery.

The contacts are numbered from 1 to 4 in a counter-clockwise order, beginning at the top-left contact.

The resistivity can be derived from a total of eight measurements that are made around the periphery of the sample with the configurations shown in Figure.



Once all the voltage measurements are taken, two values of resistivity, ρA and ρB, are derived as follows:

$$\rho_A = \frac{\pi}{\ln 2} f_A t_s \frac{(V_1 - V_2 + V_3 - V_4)}{4I}$$

$$\rho_B = \frac{\pi}{\ln 2} f_B t_s \frac{(V_5 - V_6 + V_7 - V_8)}{4I}$$

where: ρ_A and ρ_B are volume resistivity in ohm-cm; t_s is the sample thickness in cm; V_1–V_8 represents the voltages measured by the voltmeter; I is the current through the sample in amperes; f_A and f_B are geometrical factors based on sample symmetry. They are related to the two resistance ratios QA and QB as shown in the following equations ($f_A = f_B = 1$ for perfect symmetry).

Once ρ_A and ρ_B are known, the average resistivity (ρ_{AVG}) can be determined as follows:

$$\rho_{AVG} = (\rho_A + \rho_B)/2$$

Following properties of a material can be measured by this method:
1. Resistivity 2. doping type (p- or n-type)
3. sheet density of majority carriers (majority carriers per unit area)
4. charge density and doping level. 5. mobility of majority carriers.

Advantage of four probe method over two probe method

Four point probe is preferred than two-point probe as the contact and spreading resistances in two point probe are large and the true resistivity cannot be actually separated from measured resistivity. In the four probe method, contact and spreading resistances are very low with voltage probes and hence accuracy in measurement is usually very high. To measure very low resistance values, four probe method is used. The resistance of probe will be not be added to that of sample being tested. It uses two wires to inject current in the resistance and another two wires to measure the drop against the resistance.