

Resistivity by Four Probe Method

AIM

To determine the resistivity of semiconductors by Four probe Method.

APPARATUS

The experimental set up consists of probe arrangement, sample, oven 0-200°C, constant current generator, oven power supply and digital panel meter (measuring voltage and current). Four probe apparatus is one of the standard and most widely used apparatus for the measurement of resistivity of semiconductors.

This method is employed when the sample is in the form of a thin wafer, such as a thin semiconductor material deposited on a substrate. The sample is millimeter in size and having a thickness w . It consists of four probe arranged linearly in a straight line at equal distance S from each other. A constant current is passed through the two probes and the potential drop V across the middle two probes is measured. An oven is provided with a heater to heat the sample so that behavior of the sample is studied with increase in temperature.

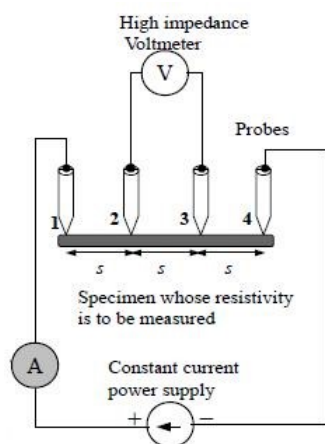


Fig:1

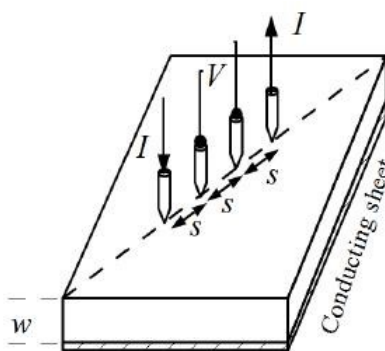


Fig:2

The figure shows the arrangements of four probes that measure voltage (V) and supply current (A) to the surface of the crystal.

THEORY

At a constant temperature, the resistance, R of a conductor is proportional to its length L and inversely proportional to its area of cross section A .

$$R = \rho \frac{L}{A} \quad (1)$$

Where ρ is the resistivity of the conductor and its unit is ohmmeter.

A semiconductor has electrical conductivity intermediate in magnitude between that of a conductor and insulator. Semiconductor differs from metals in their characteristic property of decreasing electrical resistivity with increasing temperature.

According to band theory, the energy levels of semiconductors can be grouped into two bands, valence band and the conduction band. In the presence of an external electric field it is electrons in the valence band that can move freely, thereby responsible for the electrical conductivity of semiconductors. In case of intrinsic semiconductors, the Fermi level lies in between the conduction band minimum and valence band maximum. Since conduction band lies above the Fermi level at 0K, when no thermal excitations are available, the conduction band remains unoccupied. So conduction is not possible at 0K, and resistance is infinite. As temperature increases, the occupancy of conduction band goes up, thereby resulting in decrease of electrical resistivity of semiconductor.

Resistivity of semiconductor by four probe method

1. The resistivity of material is uniform in the area of measurement.
2. If there is a minority carrier injection into the semiconductor by the current-carrying electrodes most of the carriers recombine near electrodes so that their effect on conductivity is negligible.
3. The surface on which the probes rest is flat with no surface leakage.
4. The four probes used for resistivity measurement contact surface at points that lie in a straight line.
5. The diameter of the contact between metallic probes and the semiconductor should be small compared to the distance between the probes.
6. The boundary between the current-carrying electrodes and the bulk material is hemispherical and small in diameter.
7. The surface of semiconductor material may be either conducting and non-conducting. A conducting boundary is one on which material of much lower resistivity than semiconductor has been plated. A non-conducting boundary is produced when the surface of the semiconductor is in contact with insulator.

Fig: 2 show the resistivity probes on a die of material. If the side boundaries are adequately far from the probes, the die may be considered to be identical to a slice. For this case of a slice of thickness w and the resistivity is computed as

Resistivity by Four Probe Method

$$\rho = \frac{\rho_0}{f\left(\frac{w}{s}\right)} \quad (2)$$

The function, $f(w/S)$ is a divisor for computing resistivity which depends on the value of w and S

We assume that the size of the metal tip is infinitesimal and sample thickness is greater than the distance between the probes,

$$\rho_0 = \frac{V}{I} \times 2\pi S \quad (3)$$

Where V – the potential difference between inner probes in volts.

I – Current through the outer pair of probes in ampere.

S – Spacing between the probes in meter.

Temperature dependence of resistivity of semiconductor

Total electrical conductivity of a semiconductor is the sum of the conductivities of the valence band and conduction band carriers. Resistivity is the reciprocal of conductivity and its temperature dependence is given by

$$\rho = A \exp \frac{E_g}{2KT} \quad (4)$$

Where E_g – band gap of the material

T – Temperature in kelvin

K – Boltzmann constant, $K = 8.6 \times 10^{-5}$ eV/K

The resistivity of a semiconductor rises exponentially on decreasing the temperature.

Applications

1. Remote sensing areas
2. Resistance thermometers
3. Induction hardening process
4. Accurate geometry factor estimation
5. Characterization of fuel cells bipolar plates

Resistivity by Four Probe Method

Procedure for Simulation

Combo Box and Sliders

- **Select Material** - This is used to select semiconductor material for doing the simulator.
- **Range of Current** - One can choose the range of current for the current source.
- **Current' Slider** - It ranges from 1mA to 200mA. (Note:The divisions in the slider is fixed as 100). If 20mA current is selected in the combo box, the slider value will range from 0mA to 20mA, with an interval of 0.2mA and if the value is 200mA in the combo box, slider value changes from 0mA to 200mA with an interval of 2mA.
- **Range of oven** - This combo box is used to fix the temperature to a particular range.
- **Oven**- Oven is used to vary the temperature upto 200⁰ C.
Set Button – It is used to fix the temperature in the oven.
Run Button – After setting the temperature, using run button we can start heating the oven.
Wait Button – It is used to stop heating the oven at a particular temperature.
Measure Button- It is used to display the present temperature of the oven.
- **Select Range Combo Box** – Options are X1 and X10.
- **Temperature slider** - it ranges from 27⁰ C to 200⁰ C. active only by clicking the Set button and become inactive after clicking Run button. If X1 is in combo box, the slider value ranges from 27⁰ C to 99⁰ C and If the value is X10 in combo box, slider value changes from 2.7⁰ C to 200 C.
- **Voltmeter Combo Box** - Options are 1 mV, 10 mV, 100 mV, 1 V, 10 V. One can select it for getting output in a particular range.

Procedure

1. Select the semiconductor material from the combo box.
2. Select the source current from the slider. Restrict the slider based on the range of current.
3. Select the Range of oven from the combo box.
4. Set the temperature from the slider.
5. Click on the Run Button to start heating the oven in a particular interval, from the default 25⁰C to the temperature that we set already Click on the Wait button to stop heating.
6. Click on the Set button to display the temperature that we set in the oven.
7. Click on the Measure button to display the present temperature in the oven.
8. Select the range of voltmeter from the combo box.
9. Measure the Voltage using Voltmeter.
10. Calculate the Resistivity of semiconductor in eV for the given temperature using equation (2) and (3).
11. A Graph is plotted with Temperature along x-axis and resistivity of semiconductor along y-axis.

Procedure for Real Lab

In real lab, four probes are placed on the sample as shown in Fig:1. Connections are made as shown in the simulator. A constant current is passed through the outer probes by connecting it to the constant current source of the set up. The current is set to 8mA. The voltage developed across the middle two probes is measured using a digital milli-voltmeter. The trial is repeated by placing the four probe arrangement inside the oven. The oven is connected to the heater supply of the set up. For different temperatures, upto 150⁰C, the voltage developed is noted and tabulated.

The distance between the probes(S) and the thickness of the crystal (W) are measured. The values of (W/S) are calculated and the value of the function f(W/S) is taken from the standard table. Using equation (2) and (3), calculate ρ for various temperatures.

Observations and Calculations

Temperature, T (K)	Voltage, V(mV)	Current, I(mA)	Resistivity , ρ (Ohm cm)

Resistivity can be calculated by using the equation given below.

Here we take,

Distance between the probes, S as 0.2cm and

Thickness of the sample, w as 0.05cm.

From standard table $f(w/S) = 5.89$

$$\rho = \frac{\rho_0}{f\left(\frac{w}{S}\right)} = \dots\dots\dots \text{ Ohm cm}$$

$$\rho_0 = \frac{V}{I} \times 2\pi S^2 = \dots\dots\dots \text{ Ohm cm}$$

Result

The resistivity of the given semiconductor by Four probe Method =Ohm cm