Measurement of Resistivity and Determination of the Band Gap of a Semiconductor

Chirag Verma
Course : B.Sc. (H) Physics - III year
College Roll Number: 31830172
University Roll Number : 18036567028

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Instructor:	Prachi Yadav

Aim

To study the temperature dependence of resistivity of a semiconductor by Four Probe method and to determine band gap of the experimental material.

Apparatus Required

The four probe arrangement, an oven, constant current generator, a constant power supply, digital panel meters for measuring the voltage and current

Diagram

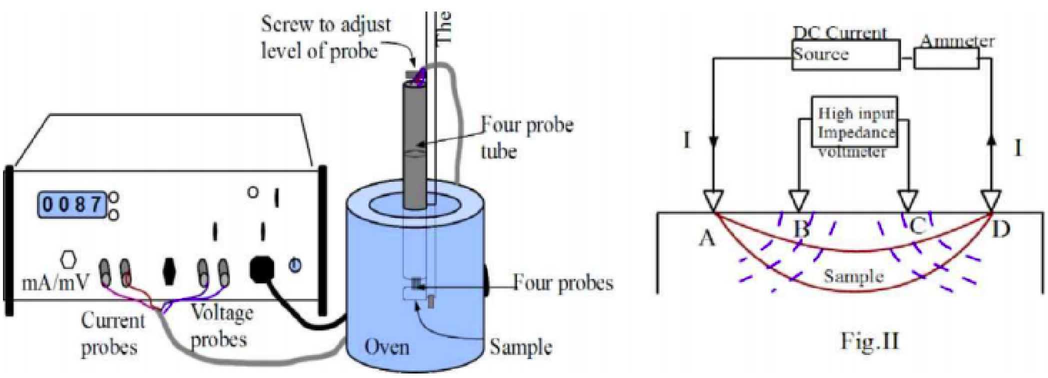

Figure 1: Schematic Diagram of Four Probe

Formula Used

$$\rho = A\exp(\frac{E_g}{2K_BT}) \tag{1}$$

where E_g is the band gap (in eV), K_B is the Boltzmann Constant, T is the absolute temperature.

Theory

At a constant temperature, the resistance, R, of a conductor is

$$R = \rho\frac{L}{A} \tag{2}$$

where R is the resistance of the conductor, ρ is the resistivity of the material of the conductor, L is is its length, and A is its area of cross-section.

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.

The 4-point probe set up (Fig.I & Fig.II) consists of four equally spaced tungsten metal tips with finite radius. Each tip is supported by springs on the end to minimize sample damage during probing. The four metal tips are part of an auto-mechanical stage which travels up and down during measurements. A high impedance current source is used to supply current through the outer two probes, a voltmeter measures the voltage across the inner two probes to determine the sample resistivity. Typical probe spacing 2 mm. These inner probes draw no current because of the high input impedance voltmeter in the circuit.

In order to use this four probe method in wafers of semiconductors it is necessary to assume that:

1. The resistivity of the material is uniform in the area of measurement
2. A non conducting boundary is produced when the surface of the crystal is in contact with an insulator

In order to use this four probe method in silicon crystals or slices it is necessary to assume that: The resistivity of the material is uniform in the area of measurement and a non conducting boundary is produced when the surface of the crystal is in contact with an insulator.

We assume that the metal tip is infinitesimal and sample are semi infinite in lateral dimensions. For bulk samples where the sample thickness, w ¿¿ s , the probe spacing, we assume a spherical protrusion of current emanating from the outer probe tips. The resistivity is computed to be:

$$\rho_0 = \frac{V}{I} * 2\pi s \tag{3}$$

where V is the floating point potential difference between the inner probes, I is the current through outer pair of probes, s is the spacing between the point probes, and ρ_0 is the resistivity . For the case of a nonconducting bottom on a slice the resistivity is computed from:

$$\rho = \frac{\rho_0}{f(\frac{w}{s})} \tag{4}$$

where f is a divisor for computing resistivity which depends on the value of w and s.

Now, on taking Logarithm in eq.(1), we get:

$$\ln\rho = \ln A + \frac{E_g}{2K_B T} \tag{5}$$

Let $\ln A = C$, therefore:

$$\log\rho = C + (\frac{1}{2.3026 * 10^3})(\frac{E_g}{2K_B})(\frac{10^3}{T}) \tag{6}$$

hence, if a graph between $\log\rho$ and $\frac{1000}{T}$ is plotted, we get a straight line.

Observations

Semiconductor wafer material : Silicon
Spacing Distance between the probes, $s = 0.2$ cm
Thickness of the sample $w = 0.05$ cm
$f(\frac{w}{s}) = 5.89$ (Noted from the standard table)
Current , I = 6mA

S.No.	**Temperature** T (deg C)	**Voltage across the inner probes** (mV)	**1000/T** K^{-1}	**Resistivity** $\rho = \frac{V}{I}\frac{2\pi s}{f\frac{w}{s}}$ ohm-cm	log ρ
01	28	0.7429	3.32	0.0264	-1.578
02	30	0.7269	3.30	0.0258	-1.588
03	32	0.7115	3.27	0.0252	-1.598
04	34	0.6967	3.25	0.0247	-1.607
05	36	0.6823	3.23	0.0242	-1.616
06	38	0.6684	3.21	0.0237	-1.625
07	40	0.6550	3.19	0.0232	-1.634
08	42	0.6420	3.17	0.0228	-1.642
09	44	0.6249	3.15	0.0223	-1.651
10	46	0.6172	3.13	0.0219	-1.659
11	48	0.6054	3.11	0.0215	-1.667
12	50	0.5940	3.09	0.0211	-1.875
13	52	0.5829	3.07	0.0207	-1.684
14	54	0.5722	3.05	0.0203	-1.692
15	56	0.5618	3.03	0.0199	-1.701
16	58	0.5517	3.02	0.1960	-1.707
17	60	0.5419	3.00	0.0192	-1.716
18	62	0.5323	2.98	0.0189	-1.723
19	64	0.5231	2.96	0.0185	-1.732
20	66	0.5141	2.94	0.0182	-1.739
21	68	0.5054	2.93	0.0179	-1.747
22	70	0.4970	2.91	0.0176	-1.754
23	72	0.4887	2.89	0.0173	-1.761
24	74	0.4807	2.88	0.0170	-1.769
25	76	0.4730	2.86	0.0168	-1.774
26	78	0.4654	2.84	0.0165	-1.782
27	80	0.4580	2.83	0.0162	-1.790
28	82	0.4509	2.81	0.0160	-1.795
29	84	0.4439	2.80	0.0157	-1.804
30	86	0.4371	2.78	0.0155	-1.809
31	88	0.4305	2.77	0.0153	-1.815
32	90	0.4241	2.75	0.0150	-1.823

Calculations

From performin Linear Regression on the graph of $log\rho$ vs $1000/T$, we get get the following equation of line:

$$y = 4.3028x - 3.0056 \tag{7}$$

which implies that the slope of the given curve is 4.3028. Now, the Band Gap is given as:

$$\begin{aligned} E_g &= 2.3026 * 10^3 * 2 * K_B * slope \\ &= 2.3026 \cdot 10^3 \cdot 2 \cdot 8.617 \cdot 10^{-5} \cdot 4.3028 \\ &= 1.70eV \end{aligned} \tag{8}$$

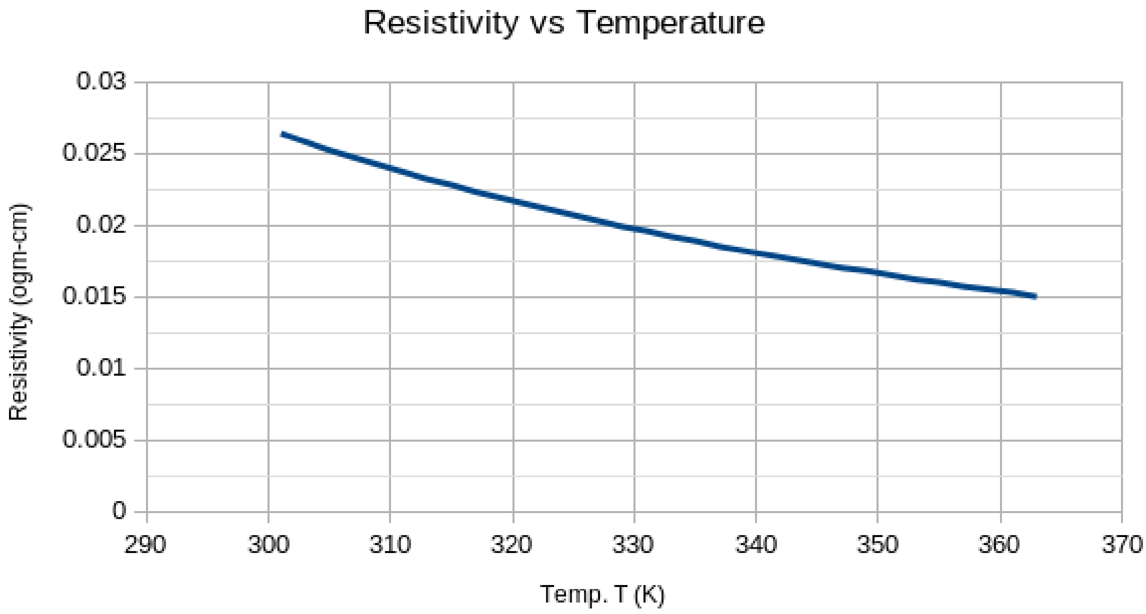

Figure 2: ρ vs T

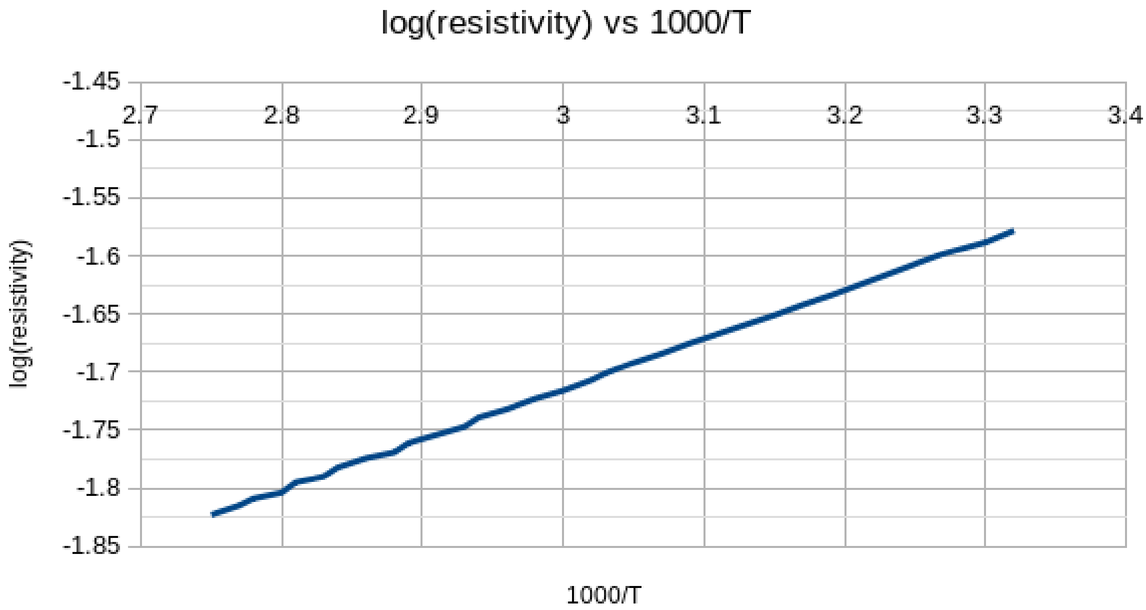

Figure 3: $\log \rho$ vs $1000/T$

Results

1. The resistivity decreases exponentially with the increase in T.
2. The energy band gap for the given semiconductor (Silicon) is = 1.70eV.

Precautions

1. The surface of the semiconductor should be flat.

2. All the four probes should be collinear.

3. The adjustment of 4-point probes should be done gently, as the semiconductor chip is brittle.

4. The voltage should be measured using inner probes only using a high impedance millivoltmeter.

5. Temperature of the oven should not exceed the limits set by manufacturer of the probes and chip.