MEASUREMENT OF ELECTRICAL RESISTIVITY OF THIN SAMPLES USING LINEAR FOUR PROBE METHOD

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March 5, 2021

1 Aim :

Aim : To measure the electrical resistivity and band gap of thin samples using linear four probe method

2 Introduction

Four Probe method is one of the standard most commonly used method for the accurate measurement of resistivity. It overcomes the problem of contact resistance and also offer several other advantages. Accurate resistivity measurement in samples having a variety of shapes is possible by this method. The pressure contacts provided in the Four Point Arrangement are especially useful for quick measurement. This setup can measure samples of reasonably wide resistivity range (micro ohm to mega ohm).

3 Theory

Four sharp probes are placed on a flat surface of the material to be measured (Fig.7). The current is passed through the two outer electrodes, and the floating potential is measured across the inner pair. If the flat surface on which the probes rest is adequately large, it may be considered to be a semi-infinite volume. To prevent minority carrier injection and make good contacts, the surface on which the probes rest, maybe mechanically lapped. The experimental circuit used for measurement is illustrated schematically in Fig. 8. A nominal value of probe spacing, which has been found satisfactory, is an equal distance of 2.0 mm between adjacent probes. In order to use the four-probe method, it is assumed that:

1. The resistivity of the material is uniform in the area of measurement.
2. If there is minority carrier injection into the semiconductor by the current - carrying electrodes, most of the carriers recombine near the electrodes so that their effect on the conductivity is negligible. (This means that the measurements should be made on surface, which has a high recombination rate, such as mechanical by lapped surfaces).
3. The surface on which the probes rest is flat with no surface leakage.
4. The four probes used for resistivity measurements are equally spaced and collinear.
5. The diameter of the contact between the metallic probes and the semiconductor should be small compared to the distance between probes.
6. The surfaces of the material may be either conducting or non-conducting.

A conducting boundary (such as copper) is one on which the sample is plated or placed. A non-conducting boundary is produced when the surface of the sample is in contact with an insulator.

$$V = \frac{\rho I}{2\pi x} \tag{1}$$

from this

$$\rho = \frac{V 2\pi x}{I} \tag{2}$$

I= 5mA x=2mm w = 0.5mm

$$\rho_c = \frac{\rho}{f_2(\frac{w}{x})} \tag{3}$$

is the corrected ρ

$$\frac{w}{x} = 0.25 \tag{4}$$

using the table given and performing cubic spline interpolation

$$f_2(0.25) = 5.578 \tag{5}$$

From the equation

$$\rho = Ae^{\frac{E_g}{2K_b T}} \tag{6}$$

we calculate and plot $log\rho_c$ vs $1/T$ from the slope of the plot we calculate E_g and the error

I have used Python to do my data analysis, I have attached the code and output below I will be able to produce the whole code if required.

In [1]:

```python
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
```

In [2]:

```python
plt.rcParams["figure.figsize"] = (8,8)
```

In [3]:

```python
data=pd.read_excel('PH17B009.xlsx')
```

In [4]:

```python
data
```

Out[4]:

	Temp	mV	Rho	Rho_c	1/T	log(rho_c)
0	303.15	511	1.283632	0.230124	0.003299	-2.481658
1	308.15	493	1.238416	0.222018	0.003245	-2.488762
2	313.15	466	1.170592	0.209859	0.003193	-2.495752
3	318.15	433	1.087696	0.194997	0.003143	-2.502632
4	323.15	397	0.997264	0.178785	0.003095	-2.509404
5	328.15	359	0.901808	0.161672	0.003047	-2.516072
6	333.15	322	0.808864	0.145010	0.003002	-2.522640
7	338.15	286	0.718432	0.128797	0.002957	-2.529109
8	343.15	255	0.640560	0.114837	0.002914	-2.535484
9	348.15	225	0.565200	0.101327	0.002872	-2.541766
10	353.15	200	0.502400	0.090068	0.002832	-2.547959
11	358.15	177	0.444624	0.079710	0.002792	-2.554065
12	363.15	155	0.389360	0.069803	0.002754	-2.560086
13	368.15	136	0.341632	0.061246	0.002716	-2.566025
14	373.15	121	0.303952	0.054491	0.002680	-2.571883
15	378.15	106	0.266272	0.047736	0.002644	-2.577664
16	383.15	94	0.236128	0.042332	0.002610	-2.583369
17	388.15	83	0.208496	0.037378	0.002576	-2.589000
18	393.15	74	0.185888	0.033325	0.002544	-2.594558
19	398.15	66	0.165792	0.029722	0.002512	-2.600047
20	403.15	58	0.145696	0.026120	0.002480	-2.605467
21	408.15	52	0.130624	0.023418	0.002450	-2.610820
22	413.15	46	0.115552	0.020716	0.002420	-2.616108

In [5]:

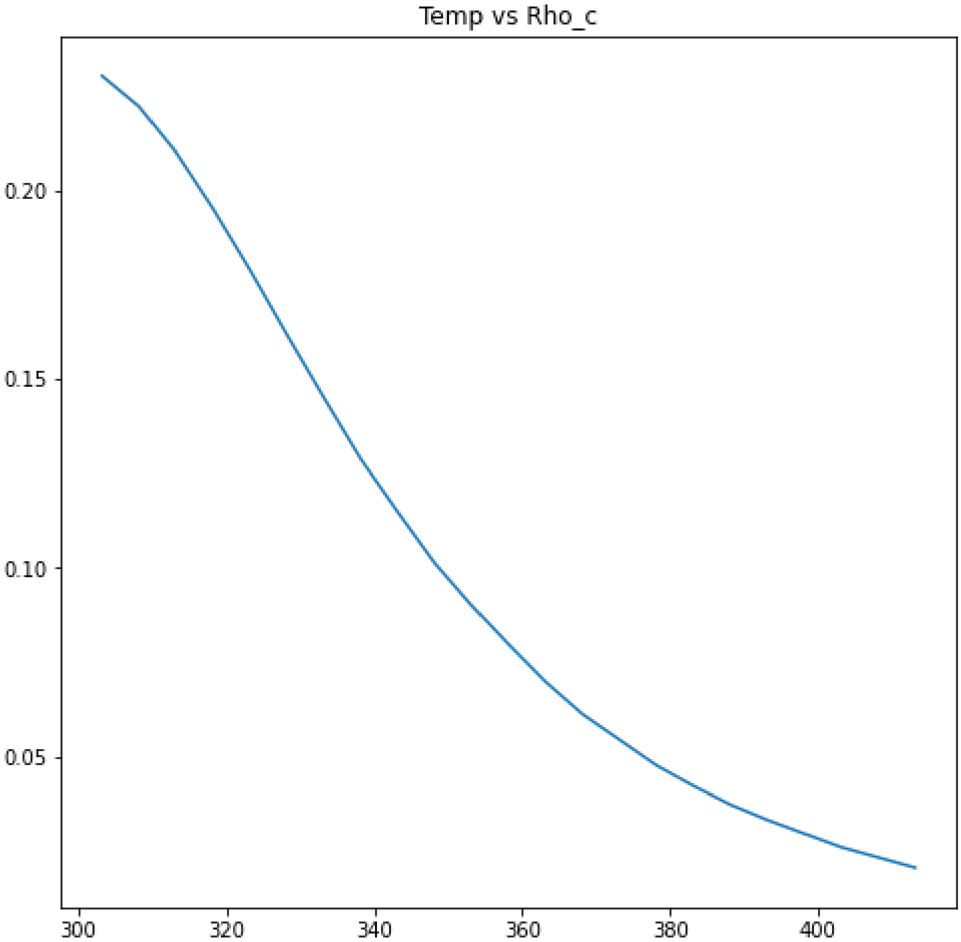
```
x=data['Temp']
y=data['mV']
```

In [6]:

```
plt.plot(data['Temp'],data['Rho_c'],'-')
plt.title("Temp vs Rho_c")
```

Out[6]:

```
Text(0.5, 1.0, 'Temp vs Rho_c')
```

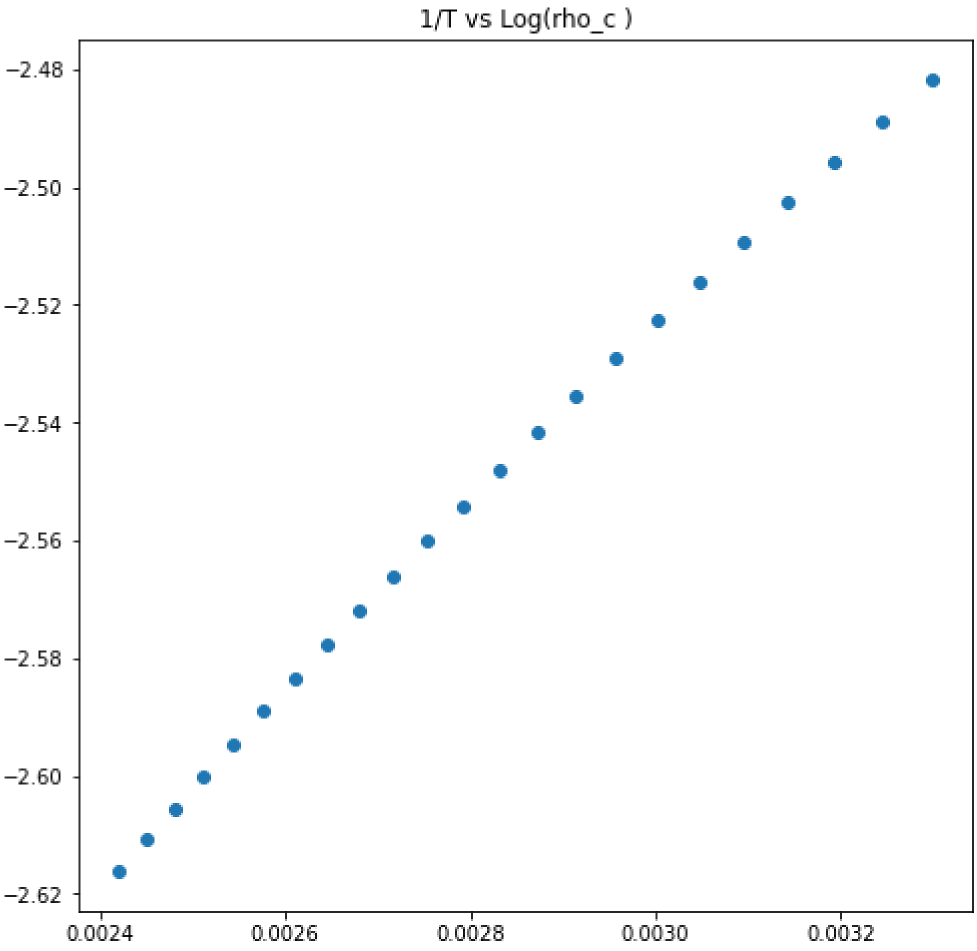


In [7]:

```
plt.plot(data['1/T'],data['log(rho_c)'],'o')
plt.title("1/T vs Log(rho_c )")
```

Out[7]:

```
Text(0.5, 1.0, '1/T vs Log(rho_c )')
```



fitting a line

In [8]:

```
x_vals = data['1/T']
y_vals = data['log(rho_c)']
```

In [9]:

```
def obj(x,m,c):
    return (m*x+c)
```

In [10]:

```
from scipy.optimize import curve_fit
```

In [11]:

```
popt,_ = curve_fit(obj,x_vals,y_vals)
```

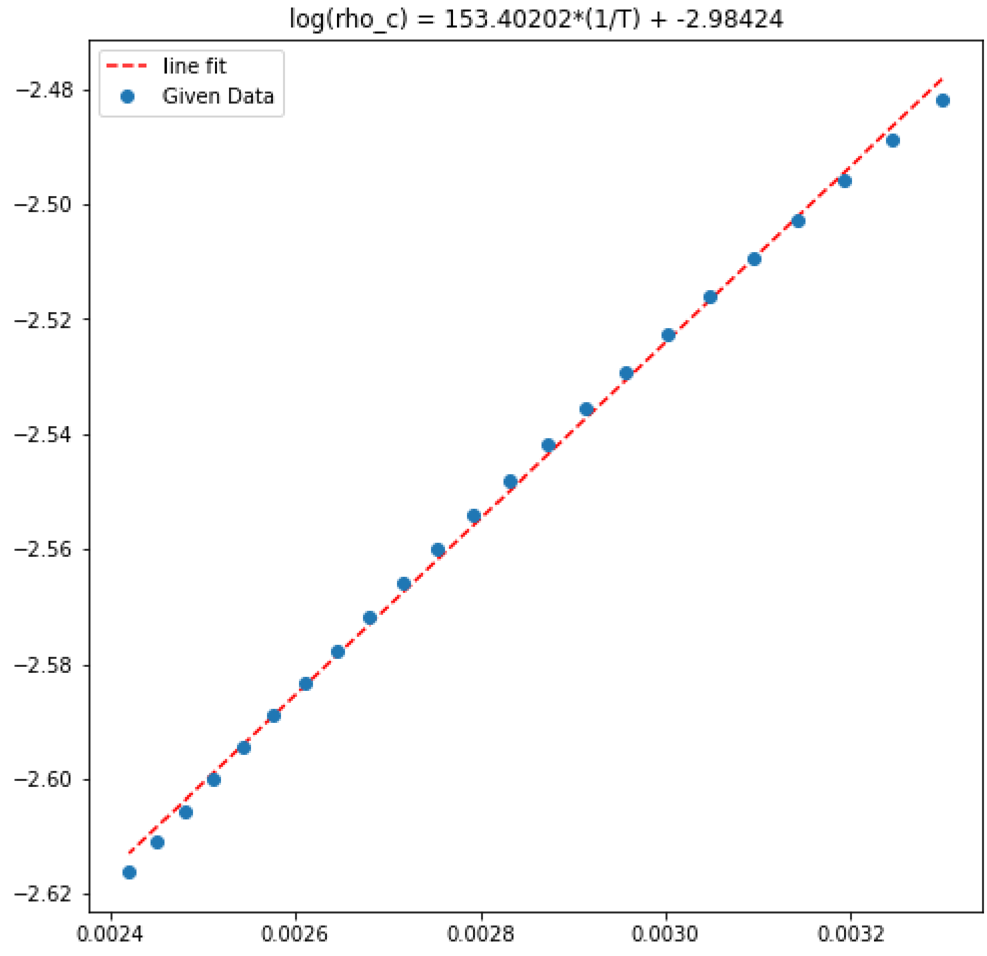
In [12]:

```
m,c=popt
print("log(rho_c) = %.5f*(1/T) + %.5f " %(m,c))
```

```
log(rho_c) = 153.40202*(1/T) + -2.98424
```

In [13]:

```
x= data['1/T']
y=m*x+c
plt.plot(x,y,'--',color='red',label= "line fit")
plt.plot(data['1/T'],data['log(rho_c)'],'o',label="Given Data")
plt.title("log(rho_c) = 153.40202*(1/T) + -2.98424")
plt.legend(loc="upper left")
plt.show()
```



$E_g = slope * 2 * K_b$

In [14]:

```
Eg = m * 2 *8.617333262*(2*10**-4)
print("Value of Eg = ",Eg, "eV")
```

```
Value of Eg =  0.5287665390440575 eV
```

Eg = 0.5287665390440575 eV

In [15]:

```
import math
A = math.exp(c)
print(A)
```

```
0.05057809182622759
```

Error in the fit is

In [16]:

```
from sklearn.metrics import mean_squared_error
mse= mean_squared_error(data['log(rho_c)'],y)
mse
```

Out[16]:

```
2.841613091626016e-06
```

Error = 2.841613091626016 e-04

In [ ]:

```
```

4 Sources of error

Sources of Error
1. The thickness of the foil.
2. The formula for is valid for semi-infinite /very large surface in comparision with the probe distance.
2. Variation of doping in the sample

5 Error Analysis

Error was calculated from the fit of the equation and the line using mean squared error as a metric. mean squared error is calculated by considering the distance from the point to the best fit line.

Error from the slope was 2.841613091626016 e-02

relative error percentage is

$$\frac{\delta(E_g)}{E_g} * 100 = \frac{0.00282}{0.5287} * 100 \tag{7}$$

which is 0.53

6 Conclusion

The value of the Bandgap was calculated to be 0.5287665390440575 eV with and error of 2.841613091626016 e-02 and relative error percentage of 0.53