ECE 230L - LAB 2

SILICON WAFER CHARACTERIZATION
RESISTIVITY, CARRIER CONCENTRATION, MOBILITY

Contents

Calculating Resistivity from Probe Measurement

The four-point probe Van der Pauw method that was used in the SMIF provided a sheet resistance value. This value was calculated by the instrument by providing a small current (I) through the 4 probes which are equally spaced on the sample and measured the voltage (V) across the two inner probes. The V/I values reported by the instrument are in units of Ohms (Ω). These values are called the sample's sheet resistance. For thick semiconductor samples like the ones measured in the SMIF—where the thickness of the wafer (W) is much smaller than the width and length of the sample—the resistivity of the sample is given by the equation

$$\rho = \frac{V}{I} t \tag{1}$$

where V/I is the sample's sheet resistance (Ω) and t is the sample's thickness (cm).

1 Objectives of this Laboratory

The objectives of this laboratory session are as follows:

- Using wafer thickness, determine the resistivity of Silicon wafers
- Determine Carrier Concentration of Silicon Wafers
- Determine μ of Silicon Wafers
- Obtain class data and average class values
- Determine number and values of doped wafers used—determine σ of each

Below, we have included a table with all of the symbols used in this lab manual and their definitions for your convenience.

Table 1: Relevant notation used throughout lab manual

Symbol	Definition	Unit
R	Resistance	Ω
L	Length	cm
A	Area	cm^2
t	Thickness	cm
I	Current	A
V	Voltage	V
ρ	Sample resistivity	Ω-cm
e	Magnitude of the electronic charge	C
μ_p	Hole mobility	cm^2/V_s
μ_n	Electron mobility	cm^2/V_s
n, p	Carrier concentration	cm^{-3}
N_A	Acceptor Concentration	cm^{-3}
N_D	Donor Concentration	cm^{-3}
N_I	Impurity Concentration	cm^{-3}

2 Determining Carrier Concentration for Resistivity Data

All of the samples measured in the SMIF were p-type Boron doped. To determine the carrier concentration, N_A, a few assumptions need to be made.

Assumptions:

1. $\mu_p = 480$ cm$^2/V_s$ (see Table 5.1, pp. 158 in Neaman text)
2. $N_D = 0$
3. Complete ionization

Along with these assumptions, we can use

$$\rho = \frac{1}{e(\mu_n n + \mu_p p)} \tag{2}$$

to determine carrier concentration. Here, e is the magnitude of the electronic charge, which is always 1.6×10^{-19} C.

Given the above assumptions, the equation for ρ reduces to

$$\rho = \frac{1}{e\mu_p N_A}. \tag{3}$$

☐ Calculate the carrier concentration, N_A, for the entire class data set. Since we are assuming that $N_D = 0$, the N_A value is exactly the impurity concentration, N_I.

3 Plot of Resistivity vs. Impurity Concentration

Plots of resistivity, ρ versus impurity concentration, N_I are called Irwin curves. They are used to estimate the carrier concentrations of samples once the sample's resistivity is known.

☐ Plot on a log-log scale the resistivity, ρ versus impurity concentration, N_I (in this case, the same as the carrier concentration, N_A) for the class data set. Your plot should resemble Figure 5.4 on pp. 165 of the Neamen text. Remember that the SMIF samples were all p-type (Boron) doped. This plot should have many values of ρ and N_I based on the class data.

☐ Determine a curve-fit to this data from the above plot including $\pm$ error ranges. Justify the $\pm$ error ranges used. Does the expected error range vary with carrier concentration?

4 Estimating expected Resistivity given a Carrier Concentration

With a plot of resistivity, ρ, versus impurity concentration, N_I, it should be possible to extract either ρ or N_I given the other.

☐ For a Si p-type (Boron) doped Carrier Concentration, N_A of 1×10^{17} cm^3, what range of Resistivity, ρ, values would you expect to obtain from this sample? Use your class averaged data plot and curve-fit from Section 3 to answer this question. Note that a range of resistivity is specified, so the $\pm$ error range must be used.

5 Device Performance based on Doping and Sample Data

The resistance, R, of a sample can be determined based on its resistivity, ρ, given the sample cross-sectional area, A, and length, L. The equation for determining Resistance from resistivity is the following (see Neaman Section 5.1.3 pp. 164):

$$R = \frac{\rho L}{A} \tag{4}$$

☐ For a die-sized portion of a wafer just like the ones measured in class, with cross-sectional area $A = 10^{-6}$ cm^2 and length $L = 0.001$ cm of the Si p-type (Boron) doped sample above—with Carrier Concentration N_A of 1×10^{15}cm^3 and a resistivity range as determined in Section 4 based on class-measured data—in an applied voltage of 5 V, determine the range of expected currents that would flow through this die.

Submit the answers to the questions marked by a square (☐) along with all of the other below-listed items in the rubric in your Lab X write-up.

Table 2: ECE 230L Laboratory 2 Grading Rubric

Criteria	Points Possible
Determining Carrier Concentration for Resistivity Data	**10**
Data set	10
Plot of Resistivity vs. Impurity Concentration (Irwin curve)	**50**
Plot	10
Curve-fit	10
$\pm$ error range specified	15
Justification for error range	15
Estimating expected Resistivity given Carrier Concentration	**20**
Range of resistivities specified	15
Device Performance based on Doping and Sample Data	**20**
Current range specified from data	15
Total	**100**