

# ECE 230L - LAB 2

## SILICON WAFER CHARACTERIZATION RESISTIVITY, CARRIER CONCENTRATION, MOBILITY

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## 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 ( $\Omega$ ). 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 ( $\Omega$ ) 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  $\mu$  of Silicon Wafers
- Obtain class data and average class values
- Determine number and values of doped wafers used—determine  $\sigma$  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	$\Omega$
$L$	Length	cm
$A$	Area	$\text{cm}^2$
$t$	Thickness	cm
$I$	Current	A
$V$	Voltage	V
$\rho$	Sample resistivity	$\Omega\text{-cm}$
$e$	Magnitude of the electronic charge	C
$\mu_p$	Hole mobility	$\text{cm}^2/V_s$
$\mu_n$	Electron mobility	$\text{cm}^2/V_s$
$n, p$	Carrier concentration	$\text{cm}^{-3}$
$N_A$	Acceptor Concentration	$\text{cm}^{-3}$
$N_D$	Donor Concentration	$\text{cm}^{-3}$
$N_I$	Impurity Concentration	$\text{cm}^{-3}$

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

Along with these assumptions, we can use

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

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

Given the above assumptions, the equation for  $\rho$  reduces to

$$\rho = \frac{1}{e\mu_p N_A}. \quad (3)$$

- ☐ 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,  $\rho$  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,  $\rho$  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  $\rho$  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,  $\rho$ , versus impurity concentration,  $N_I$ , it should be possible to extract either  $\rho$  or  $N_I$  given the other.

- ☐ For a Si p-type (Boron) doped Carrier Concentration,  $N_A$  of  $1 \times 10^{17} \text{ cm}^{-3}$ , what range of Resistivity,  $\rho$ , 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,  $\rho$ , 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):

$$R = \frac{\rho L}{A} \quad (4)$$

- ☐ For a die-sized portion of a wafer just like the ones measured in class, with cross-sectional area  $A = 10^{-6} \text{ cm}^2$  and length  $L = 0.001 \text{ cm}$  of the Si p-type (Boron) doped sample above—with Carrier Concentration  $N_A$  of  $1 \times 10^{15} \text{ cm}^{-3}$  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 ( $\square$ ) 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
<b>Determining Carrier Concentration for Resistivity Data</b>	<b>10</b>
Data set	10
<b>Plot of Resistivity vs. Impurity Concentration (Irwin curve)</b>	<b>50</b>
Plot	10
Curve-fit	10
$\pm$ error range specified	15
Justification for error range	15
<b>Estimating expected Resistivity given Carrier Concentration</b>	<b>20</b>
Range of resistivities specified	20
<b>Device Performance based on Doping and Sample Data</b>	<b>20</b>
Current range specified from data	20
<b>Total</b>	<b>100</b>