Chapter 2

Materials and Devices
2.1 Introduction

Materials and Devices is concerned with how semiconductor devices, such as transistors, diodes, and sensors work and how they are built. Introductory courses cover the physics and properties of electronic materials: semiconductors, metals and insulators, and how these materials are combined to form electronic devices. Higher level courses specialize in particular areas such as optoelectronics, semiconductor processing, magnetics, or sensors. In the undergraduate semiconductor fabrication laboratory, students learn to use semiconductor processing equipment in the clean room to fabricate and test their own diodes and transistors.

2.2 Section Overview

A resistor is a two-terminal component which resists current flow in a circuit. The resistor depends on the resistivity of the material, length and cross-sectional area. Resistance has a unit of Ohms (\( \Omega \)). See Figure 2.1.

\[
Resistance = Resistivity \times \left( \frac{Length}{CrossSectionalArea} \right) \quad R = \rho \frac{L}{A}
\]

Figure 2.1: Finding Resistivity

2.3 Objectives

- Resistance Basics
- Use the digital multimeter
- Graph data
- Potentiometers

2.4 Materials

- Digital Multimeter
- Conductive Paper
- Teensy2.0
- Female-female prototyping wires
2.5 The Digital Multimeter

Digital multimeter (DMM) is a useful measurement tool. There are three settings in a typical DMM; Voltmeter measures potential difference (voltage), Ohmmeter measures resistance, and Ammeter measures current.

2.5.1 Using a Digital Multimeter

Setting up a dial switch: Choose an appropriate switch position for the measurement. Refer to Figure 2.2 for a description of each switch position. Make sure to set the dial switch before measuring, doing something like trying to measure voltage when the dial is set to current can possibly blow the fuse in your DMM.

Figure 2.2: DMM Showing the Meter Switches
2.5.2 Using a DMM to measure Voltage and Current

1. To measure potential difference (voltage), the voltmeter is connected in parallel with the component. In Figure 2.3, the voltmeter is connected in parallel with a resistor.

![Figure 2.3: Measuring Voltage](image)

2. To measure current, the circuit must be broken to allow the ammeter to be connected in series in the circuit. The ammeter becomes part of the circuit's connection. See Figure 2.4

![Figure 2.4: Measuring Current](image)

3. To measure resistance, the component being measured must be removed or the power source must be disconnected, and place the ohmmeter in parallel with the component. See Figure 2.5

![Figure 2.5: Measuring Resistance](image)
2.5.3 Measuring Resistance

An ohmmeter is one of the useful functions in the digital multimeter (DMM). Since the ohmmeter uses its internal battery to conduct the resistance test, there must not be any power sources connected to the circuit. To test for resistance follow the procedures below:

1. Set the DMM to the Resistance or Ohms measurement setting, which is the region marked with “Ω”, “R” or “Ohms”. Figure 2.6 highlights the Ohmmeter region for an RSR MAS830 DMM. Note that your DMM might be different than the one in the picture.

2. Connect the black probe to the jack marked “COM”, “GND”, or “-”

3. Connect the red probe to the jacked marked “VΩmA” as shown in Figure 2.6 (marked “Ω”, “R” or “Ohms”).

4. Put the leads from the DMM on each side of the component being measured as shown in Figure 2.7. If the DMM screen displays “1.”, this indicates that the range setting should be higher or the resistance is more than the maximum which can be measured on the range setting. For example, the Ohmmeter’s rotary switch is at the “2k” mark. It should be changed to “20k” for a proper reading. If the DMM screen displays “.000”, this indicates that the range setting should be lower. For example, the Ohmmeter’s rotary switch is at the “200k” mark. It should be changed to “20k” for a proper reading. Continue adjusting the range setting as necessary.

5. For reading the value, each range of the Ohmmeter has a letter indicating the prefix for the unit. For example, the range setting of “20k” indicates that the unit is in Kilo Ω. Figure 2.7 shows that the Ohmmeter is set at “20k” range, the reading on the screen is “9.18.” This means the resistance should be roughly 9.18KΩ.

6. Be sure hands are not making contact with the tip of the probes because a body appears as another resistor in parallel with the one being measured.
2.6 Procedures

In this section, different lengths and widths of conductive paper will be used to explore the resistance equation. Using scissors, cut the piece of paper provided as shown. Set the strip marked “Keep for Lab 3” aside, as it is needed for the next lab, where a variable resistor is used to make a mini piano circuit.

![Cut the paper as shown.](image)

**Figure 2.8:** Cut the paper as shown.

### 2.6.1 Length

Explore the relationship between resistance and length by using strips numbered 1, 2, and 3. In this test, resistivity and cross sectional area are constant and length is varied. Measure the resistance of each of these strips using a DMM.

\[
R = \rho \frac{L}{A}
\]

Strip 1 Resistance = \(\Omega\)
Strip 2 Resistance = \(\Omega\)
Strip 3 Resistance = \(\Omega\)

### 2.6.2 Width

Explore the relationship between resistance and cross sectional area by using strips numbered 4, 5, and 6. Resistivity, length, and thickness are constant. The width portion of cross sectional area is varied. Measure the resistance using the digital multimeter. *(Hint: Set the rotary switch to “200k”)*

\[
R = \rho \frac{L}{W \times T}
\]

Strip 4 Resistance = \(\Omega\)
Strip 5 Resistance = \(\Omega\)
Strip 6 Resistance = \(\Omega\)
2.6.3 Thickness

Using strips 1, 5, or 7, explore the relationship between cross sectional area and resistance. Measure the resistance by using a digital multimeter. Use the resistance equation to calculate the approximate thickness of the paper. Assume the resistivity constant $\rho = 2.68 \, \Omega \cdot m$. Convert all measurements to SI units before doing calculations.

$$R = \rho \frac{L}{W \times T}$$

Resistance = $\Omega$

Thickness =

2.7 Variable Resistor

In this section a variable resistor, also known as a potentiometer will be created using a strip of conductive paper. The potentiometer could be used as a variable resistor in the circuit or as a voltage divider. For this lab, the potentiometer will be used as a voltage divider. Common applications that use a potentiometer are a light dimmer switch, a power supply, and speaker volume.

1. Stick one paper clip each into the ends of two prototyping wires from the ECE 111 kit (look at figure 2.10 for a reference). Attach the other end of the wires into the VCC and GND pins on the teensy (make sure to plug the teensy into a power source).
2. Attach one paper clip to one edge of the conductive paper and the other paper clip on the opposite edge. There is now 5V across the conductive paper.

3. Use a digital multimeter to measure the voltage at each grid line by putting the black lead of a DMM at GND and pressing the red lead against the paper at each grid line (each grid line is 1cm apart).

4. Record the measurements in Figure 2.11 and graph the data using Figure 2.12.

<table>
<thead>
<tr>
<th>Measuring Point</th>
<th>Distance From Reference Point (cm)</th>
<th>Voltage (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
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<td>D</td>
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<td>E</td>
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<tr>
<td>F</td>
<td></td>
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</tr>
</tbody>
</table>

Figure 2.11: Variable Resistor Table

Figure 2.12: Voltage vs. Distance

TA Signature: _______________________
(Lab Work Complete)
2.8 Study Questions

Please type out your answers to the following questions. They will be turned in at the beginning of next lab.

1. List 3 ways the resistance of a resistor can be decreased. *(Hint: use the equation for resistance)*

2. List several products that are engineered using materials and devices concepts. Also, explain how they are related to materials and devices.

3. Find an OSU professor in the materials and devices track and describe one of their current research projects.

2.9 Challenge

Create a conductive paper potentiometer that can vary the intensity of an LED when connected in a circuit. For full points, demonstrate the working circuit and draft a schematic of the working circuit.