# Determination of the Resistivity of an Elastic Conductive Material in an RC Circuit and Applications of Flexible Strain Sensors

Zachary Morgan

Olympia High School Orlando, FL 32835

## Summary

**What is a strain sensor?**

- A strain sensor is a device used to measure how much a component distorts when an external force is applied to it.
- A strain sensor consists of a conductor or semiconductor that is fabricated into another material to form a sensor.

**How does a strain sensor work?**

- A strain sensor works by measuring the electrical resistance of the strain gauge.
- Electrical resistance is determined by the resistivity (ρ) of the material, the length (*l*) of the gauge, and the cross-sectional area (*A*) of the gauge according to the equation $R = \rho \frac{l}{A}$.
- As the strain gauge is stretched, the resistance increases. Strain sensors work by measuring the change in resistance of a gauge and correlating that change to the change in length of the gauge to determine the stress being applied to the system.

**Flexible strain sensors and their applications:**

- Flexible strain sensors are usually strain gauges bonded in an elastomer that are able to be flexed and return to their original shape.
- These sensors are useful for measuring motion of a moving object.

## Research Activities

**Calibration of Gauge Factor of a Flexible Strain Sensor:**

- In this lab activity, we took a flexible strain sensor and measured the change in electrical resistance when we applied a stress to the system.
- The sensor was made from carbon nanotubes embedded in a flexible polymer (a).
- The sensor was attached to a MTS Tensile Testing Apparatus that applied a constant stress to the sensor, stretching it a set amount per interval. (b)

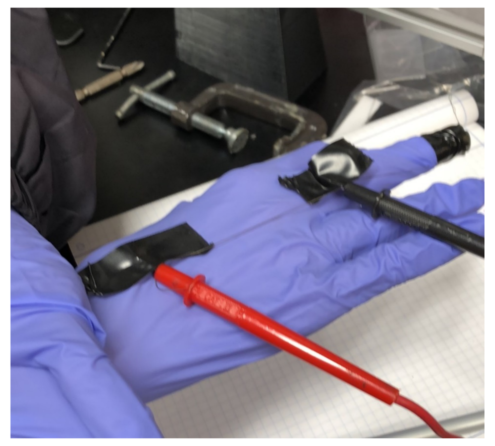
(a)

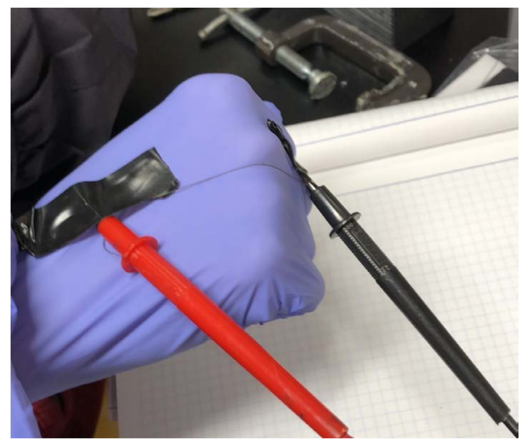
(b)

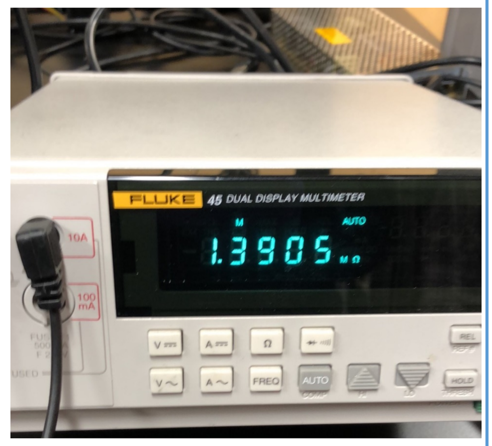
- The resistance of the sensor was measured at each length.
- The gauge factor of the sensor was calculated using the equation $\mathrm{GF} = \frac{\frac{\Delta R}{R_0}}{\frac{\Delta L}{L_0}}$

**Simulation of a Flexible Strain Sensor:**

- In this research activity, we used conductive yarn to try and create a flexible strain sensor.
- There were two types of yarn: one that released heat when an electrical current was run through it, and one that did not release much heat when an electrical current was run through it.
- We created a sensor out of a glove and a piece of the yarn (c) and measured the change in resistance of the yarn as it was stretched (d) using a multimeter (e).







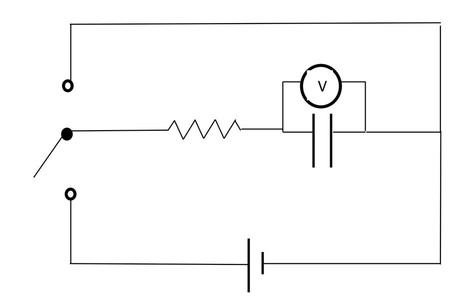

## Lesson Plan

**Day 1 (Research):**

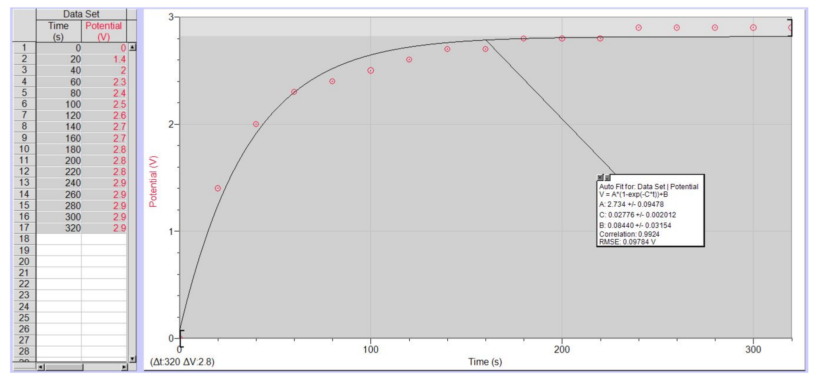
- Students will be asked to research strain gauges and how they work. They will also research types of strain gauges including flexible strain sensors.
- After 20-25 minutes, the teacher will facilitate a discussion on types of strain gauges and how flexible strain sensors work.

**Day 2 (Guided Inquiry Lab):**

- Students will wire a circuit with a capacitor, resistor, switch, and voltmeter up in the following orientation. The resistance of the resistor is known. The capacitance of the capacitor is labeled.



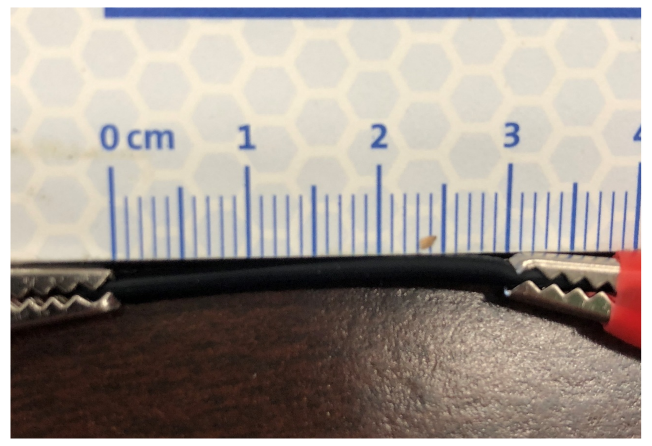

- The goal of the lab is to compare the measured capacitance to the labeled capacitance.
- Students will measure the electric potential across the capacitor over time.
- Have students graph the potential vs. time for the data and fit the curve to the equation $V(t) = V_{battery}\left(1 - e^{-t/RC}\right)$.



- Using the best fit curve and the value for the resistance, calculate the actual capacitance of the capacitor.

**Day 3 (Investigational Inquiry):**

- Students are given a piece of an elastic conductive cord and the same materials as the previous day. Students are asked to determine the resistivity of the cord and to determine the resistance per length (in centimeters) of the cord when unstretched (a). The cord can stretch to approximately 150% of the original length (b).




(a)


(b)

- While there are multiple methods to accomplish this, many will choose to use an RC Circuit as they did the previous day. If done with the RC Circuit, the results should have a similar shape as the graph from the previous day but will have different numerical values for the time constant RC.

**Final Product:**

- Students will complete a lab report for the experiments for Days 2 and 3.
- Information included:
    - Experimental Procedure Design
    - Analysis of collected data
    - Analysis for experimental errors based on results and expected results
    - Explanation of how flexible strain sensors work and their uses. Explanation of how this lab corresponds to a flexible strain sensor.

## Lesson Learned and Assumptions

- This lesson will be used at the end of the circuits unit in AP Physics C: Electricity and Magnetism.
- This lab activity is a synthesis of multiple topics covered throughout the unit and is very inquiry-based and provides students with an opportunity to design and perform an experiment.
- *Note: This lesson can be done without a capacitor for courses that cover resistance and resistivity but do not cover RC Circuits. This lesson can also be adapted to measure the current using an ammeter rather than the potential across the capacitor.
- Students should know the general concepts of resistance, resistivity, and capacitance.
- Students should know the formulas associated with RC circuits and the relationships between the resistance, capacitance, and voltage in an RC circuit.
- Students will complete multiple lab activities before the implementation of this unit. This lab activity is a synthesis of multiple topics from the electrical circuits unit.

## Implementation Strategy

**Troubleshooting Tips:**

- Ensure that students do not touch the switch or exposed metal while the capacitor is charging or discharging.
- Make sure that all wires are in proper working conditions without any internal wiring exposed.
- Make sure that the multimeter is hooked across the capacitor in parallel. If the reading of the voltage comes out negative, switch the leads of the multimeter.
- Make sure students are analyzing data with a best fit curve rather than using direct data points. Additional instruction on graphing and analyzing data may be required.

**Required Materials:**

- 100 Ω resistor (or similar resistor)
- Multimeter and wires
- 1 F capacitor (or similar capacitor)
- Adafruit conductive rubber cord stretch sensor
- 9 V battery or a power supply
- Graphing Software or Data Analysis Software
- Ruler or meterstick or digital calipers

## Acknowledgments

RET Site: COMET Program, College of Engineering and Computer Science, University of Central Florida. This content was developed under National Science Foundation grant EEC-1611019.

Advising Faculty:

- Dr. Jan Gou- Professor, Composite Materials and Structures Laboratory
- Dr. Joe Cho- Professor and RET Site Director, Nano fab and BioMEMS lab
- Dr. Damla Turgut- Professor and RET Site Co-Director, Computer Science
- Chad Hobby- Returning RET Teacher, Timber Creek High School
- Jim Ebbert- Returning RET Teacher, Deland High School

## References

- Andrea Meoni, Antonella D'Alessandro, Austin Downey, Enrique García-Macías, Marco Rallini, A Luigi Materazzi, . . . Filippo Ubertini. (2018). An experimental study on static and dynamic strain sensitivity of embeddable smart concrete sensors doped with carbon nanotubes for SHM of large structures. *Sensors, 18*(3), 831. 10.3390/s18030831 Retrieved from https://search.proquest.com/docview/2026505757
- Lin, Y., Liu, S., Chen, S., Wei, Y., Dong, X., & Liu, L. (2016). A highly stretchable and sensitive strain sensor based on graphene-elastomer composites with a novel double-interconnected network. *Journal of Materials Chemistry C, 4*(26), 6345-52. 10.1039/c6tc01925k Retrieved from http://dx.doi.org/10.1039/c6tc01925k

www.PosterPresentations.com