Wearable Electronics

12TH GRADE TECHNOLOGY

SCIENCE AND TECHNOLOGY

Bio-Electronics Grade 12
Subject Areas: Nanotechnology
Lesson: Nano-Circuit Dimensions in Fabrication
Class Time: 3 hours

Standards: HS-ETS1-2. Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering. HS-PS2-6. Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.

Overview:

Flexible circuits and their applications to the photolithography fabrication process will be crucial in the development of ***wearable technology***. The application of graphene in organic fibers impacts organic electronics, e-textiles, and wearable technologies.

Outcome:

Students will learn about and create graphite-based fibers using sodium alginate as the medium and a calcium coagulation bath. Students will then determine how to vary parameters to optimize fiber resistivity.

Introduction:

The objective of this activity is to develop techniques in the growing field of organic electronics. In the development of the nanotechnology necessary for this process, a one-atom-thick sheet of carbon graphene is less costly, lighter in weight, more flexible, more environmentally friendly, and more efficient than silicon and metal-based microelectronics. An alternative approach to creating graphene uses chemical exfoliation of graphite to create graphene-oxide. Removal of the oxygen improves conductivity along with a high-temperature annealing process. Obtaining conductivity through this process allows for functional electronic wearables.

Objectives: Students will

- Analyze models of resistivity to predict the performance of conductive fibers.
- Calculate the parameters of the resistivity of a material.
- Fabricate graphene-based organic conductive fibers.
- Compare the mechanical and electrical properties of graphene to steel.
- Determine applications for conductive fibers.

REAL WORLD CONNECTIONS

1. *Students will practice lab skills in a real setting.*
2. *Students will create organic electronics to be used as e-clothing.*

Materials List:

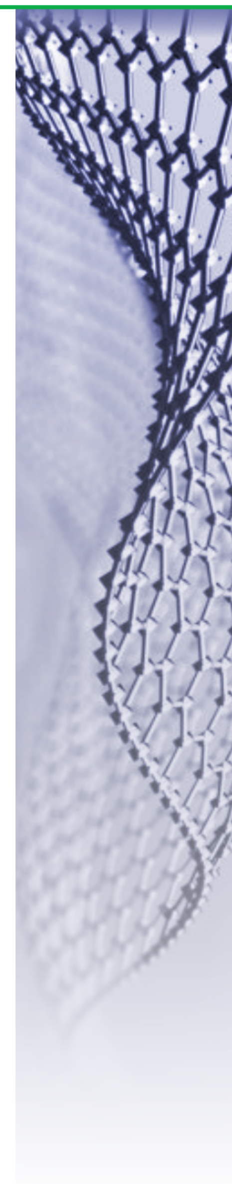
- 34 g (~1/4 cup) sodium alginate, food grade
- 10 g lab grade calcium chloride ($CaCl_2$) flakes (or substitute with road deicing pellets)
- 50 mg graphite
- food coloring (optional)
- 200 ml deionized water
- 2 glass beakers
- 2 plastic spoons or wooden spatulas
- 5 ml pipette or plastic syringe
- glass stirring rod
- paper towels
- blender, ruler(s), refrigerator, and multimeter

Reference:

"What will people wear in the future?"
The Economist
https://www.youtube.com/watch?v=u-MOAbNfmEuo

Sources:

- http://www.slideshare.net/PSFK/ps-fk-future-of-wearable-tech-summary-presentation
- http://cutecircuit.com/wearable-technology/#after_full_slider_1
- http://phandroid.com/2015/05/29/project-jacquard-smart-clothes/



Plan: Create a process for making organic conductive fibers.

Wearable, flexible electronics tend to be thin, lightweight, stretchable and comfortable. Photolithography is the process used to fabricate flexible wearable electronics. A thin conductor foil is adhered to a glass substrate coated with polyimide, a photo-sensitive polymer. When exposed to UV light, a chemical reaction follows. Students will measure the circuit images during the fabrication process. The data will then be analyzed to determine the significance of the changes.

Constraints:

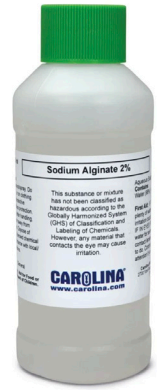
1. Your test fiber must be at least 3 cm in length.
2. Your fiber should be as thin as possible, with a uniform diameter.
3. Your fiber should have minimum resistivity.

Cautions:

- Sodium alginate is a food additive and is harmless if ingested.
- Graphite can be dangerous if inhaled or comes in contact with the eyes, so precautions should be taken in its handling. Ensure graphite is scooped carefully and not poured.
- Wear gloves, wipe down surfaces afterward with a wet cloth.
- Food coloring may be used to color the alginate and is safe for ingestion.

Preparation:

- 2 g powdered sodium alginate should be poured into blender for every 100 ml of warm water. Pouring slowly while blender is already on will yield best results.
- Food coloring can be added at this stage
- Refrigerate overnight to deter bacterial growth



Making the fibers:

1. Prepare calcium bath with deionized water and 6 g $CaCl_2$ flakes.
   (Road deicing pellets can be used instead.)
2. Mix graphite into sodium alginate using a spoon or wooden spatula.
   Do not pour. Avoid handling graphite that will result in airborne particles.
3. Draw alginate/graphite suspension into a plastic 5 ml pipette or a plastic syringe.
4. Extrude alginate/graphite at a constant rate into the calcium solution.
5. Use a clean spoon or glass stirring rod to draw the "fiber" out of the solution.
   Dry on a paper towel.

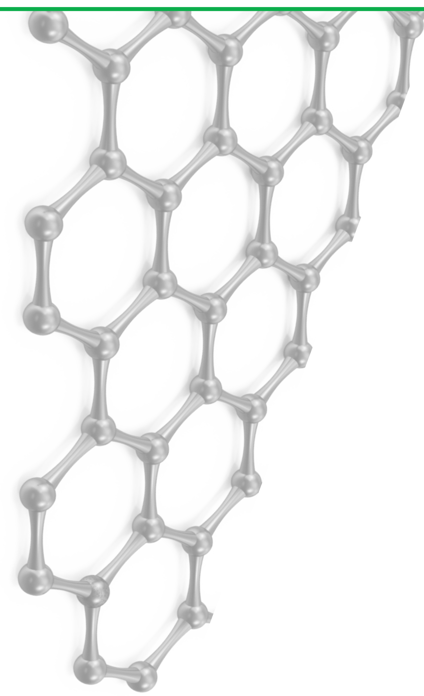
- To test the resistance, use a multimeter set on 200 kΩ and be sure the tips of the leads are inserted into (not on top of) the fiber at a predetermined or measured length.
- The measured length of the fiber for use in calculating resistivity is the distance between the leads when measuring resistance.
- To measure the diameter of the fiber, use a millimeter ruler or a light microscope set on the lowest setting with a transparent ruler positioned on the stage.

Procedure:

Calculate resistivity for each fiber created and measured. Factors to be varied:

- fiber width
- graphite concentration
- calcium concentration (although the level of calcium ions in the bath will reduce after each fiber is created)
- viscosity (water content) of sodium alginate

The goal is to optimize for smallest resistivity. As you test fibers, determine factors responsible for lowest resistivity and optimize them, given the constraints and availability of your resources.



Data Acquisition (Record data):

- Use a measuring tape or ruler to measure the length of the fibers produced.
- Photograph the fiber next to a ruler.
- Measure the resistance of each fiber. Photograph the measurement of the resistance, which is captured using a multimeter.
- Calculate the resistivity for each fiber. Determine the fiber that presents the most ideal properties.
- Photograph the sheet used to make the calculations of cross-sectional area and the resistivity.
- Photograph the calculations page with data for at least five fibers.
- Write a conclusion paragraph that includes the following components. Remember to use technical vocabulary learned as part of the lesson.
    - State the resistivity of the fiber that presented the best values.
    - State what processing techniques, parameters, and quantities led to the ideal resistivity values. Use the date in your table to support the conclusions described in your paragraph.
    - Explain why resistivity is not the same thing as resistance.
    - Is it important to have a low or high resistivity in fibers? Explain your answer.
    - Explain why graphene and graphite fibers are called organic. Why can these materials be used to produce electronics?
    - Finish the sentence: *Graphene is used in the development of electronic fibers because it has the following properties:*

      ____

      ____

Self-Evaluation:

a. Have you produced a fiber with lowest resistivity?

b. Can you explain what factors lead to this optimal state?

c. What is the design engineering problem that your team is solving?

d. What are the design constraints?

e. What will be observed? What will be measured?

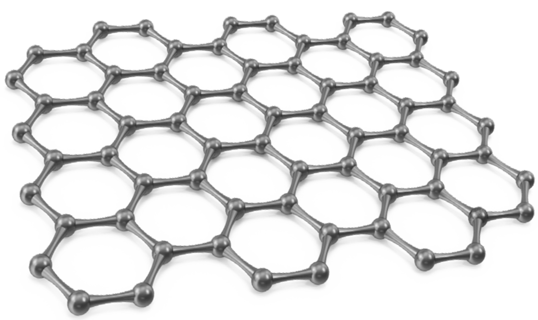
f. What will be held constant and what will be optimized?

Vocabulary:

anneal:
To heat a material (usually metal or glass) and allow it to cool slowly, in order to remove internal stresses and toughen it.

conductivity:
The property of a material that conducts electricity; inverse of resistivity.
electrical resistance: The ability of a material to resist the flow of electrons, measured in ohms.

graphene:
A layer of carbon atoms in a single sheet that is one atom thick.



graphite:
Layers of carbon assembled in a 3D structure; coal is an example of a graphite structure.

nanoscale:
A term that refers to objects that are 1 billionth of a meter in size; used to measure scales at the atomic level.

organic:
Carbon-based material or molecule.

organic electronics:
Field of materials science in which polymers and other small molecules are studied for conductivity and other properties.

resistivity:
The property of a material that resists electric current; inverse of conductivity.

Review/Assesment:

Have students work on their own or in small groups to answer the following:

- What is graphene? What makes graphene different from graphite?
  Answer: Graphene is a one-atom-thick (2D) layer of graphite (3D).
- Why is graphene considered a "wonder material?"
  Answer: Because it has remarkable properties in electrical resistance, thermal conductivity, transparency, strength, and flexibility
- Why is calcium used in the graphene coagulation bath?
  Answer: Because it has a 2+ charge and can bond with two graphene sheets at a time, effectively connecting them to one another. (In this lab, the calcium will also crosslink the sodium alginate polymer chains together, providing a network that suspends the graphite particles.)
- What is the biggest challenge to using graphene in commercial processing at this time?
  Answer: Graphene is extremely difficult to make in large quantities.