Lesson Plan

Title
Photolithography

Primary Subject Area
Chemistry

Grade Level
High School (10 or 11)

Overview
Students will perform “photolithography” using sun sensitive paper (SSP). They will discuss the chemical processes behind their exposures, the use of sun as a reactant, the solubility of different chemicals, and design a “mask.” Similarities will be drawn between their experience and that of industry as they learn about actual photolithography.

Approximate Duration
~3 days

MA Frameworks
7.1 Describe the process by which solutes dissolve in solvents.
7.5 Identify the factors that affect the rate of a chemical reaction (temperature, mixing, concentration, particle size, surface area, catalyst).
SIS1. Make observations, raise questions, and formulate hypotheses.
*4.4 Identify and explain alternatives to nonrenewable energies (e.g., wind and solar energy conversion systems).

Interdisciplinary Connections
Art (photography), green technology (solar energy), engineering (photolithography, microfabrication)

Lesson Objectives
-Design and perform a simulation of photolithography using SSP
-Explain the chemical process (reactions, solubility, solar energy, reaction rate affected by amount of sun) of development used in SSP
-Compare photographic processes (development, solubility) to photolithographic industrial processes (development, deposition, liftoff, solubility)

Lesson Materials and Resources
-Sun sensitive paper (http://www.stevespanglerscience.com/product/sun-sensitive-paper), 1 per student
-Masks (overheads, leaves, or let students brainstorm ways to create a mask)
-Sunny day (cloudy takes 5-20 minutes to develop, sunny takes 2-5)
-Water for rinsing, optional clothespins/line for drying
-Cleanroom models, diagrams showing process
-Optional: old black and white photo negative and black and white photo

Technology Tools and Materials
-Cleanroom access, photos/diagrams/models
-Example silicon wafer and/or other item made in cleanroom
-Sun

Background Information
Black & White photography makes use of positive photo resist. When you take a picture, you receive a negative, then use that negative to expose your photo paper. The lighter an area on the negative, the darker the area on the photo paper. This photo then goes through a process called fixing where the paper is rinsed in a certain chemical to halt the exposure process, then rinsed off with water to get rid of the chemicals.

Sun sensitive paper also uses positive photo resist. There are two chemicals on its surface that react together in the presence of UV light from the sun, one of which is **iron (III) hexacyanferrate (III)**, **$Fe[Fe(CN)_6]$**, or **Berlin Green**. Their product is colorless, so you can’t see it right away. The chemical used in this process of fixing is just water. The original blue molecule—**Berlin Green**—is water soluble, so any that is left behind on the paper (that is, anything that wasn’t exposed) just washes away to reveal white. However, the colorless molecule actually reacts with the water to create a new deep blue molecule called **iron (III) hexacyanoferrate(II)**, **$Fe[Fe_4(CN)_6]_3$**, or **Prussian Blue**. So the final image is just a white picture on a deep blue background.

The photolithography process at BU is also a positive photo resist process. In the cleanroom, we take a silicon wafer and use a "spinner" to coat it with an adhesive, HMDS. This makes it easier for the photo resist to stick to the wafer's surface. We then spin the wafer once again to get a smooth, even coating of the photo resist. This is then exposed to a specific wavelength of light (in our case, UV) where all the areas exposed lose the photo resist. We rinse the wafer in a developer solution in order to get the photo resist away (reaction → solubility) then rinse it off with distilled water and dry it with nitrogen gas. This creates a wafer that has dark photo resist wherever it wasn't exposed and plain wafer wherever it was exposed.

Unlike regular photography, industry is often looking to use these wafers in processes called "microfabrication," ie miniature electronics, computer chips, nanotechnology. The wafer with the resist on it is just a template where we want to place metal. The empty spaces are where we want to place the metal, and the photo resist is where we want empty spaces—much like a photo's negative. So we place titanium all over the wafer, place gold on top of that, then get rid of the photo resist using acetone. The photo resist is soluble in acetone, but the titanium is not. Any titanium bonded to the photo resist will rinse away with it in the acetone bath, but any that is bonded straight to the wafer is not. Thus, at the end of the process we are left with a wafer that has gold where it used to have empty space, and empty space where it used to have photo resist.

Useful Vocabulary

New Vocabulary Word	Meaning
Photolithography	Photographic (use of light) printing using a metal plate with a completely smooth surface
Microfabrication	Fabrication (creation) of miniature structures on the micrometer scale
Exposure	Allowing a chemical (normally attached to a piece of paper) to react with light and form a new chemical

Essential Questions to be answered; Grand Challenges

How does photography work?
What is the difference between dissolving and a reaction?
How are computer chips made?

Misconceptions

Everything can be dissolved in water.
Longer time == always better in a reaction.
Dissolving is a chemical reaction.
Converting one molecule to a next using solar energy is not a chemical reaction.
Photography does not involve any chemistry.
Computer chips are put together using tiny machines.

Lesson Procedures

Day 1

Warm-up: This is a black/white negative and this is its accompanying photograph. How did the negative become the photograph?

Activity: Sun Photography

- Have students design "masks" as homework. (This year, might have a contest with Helen and the cleanroom staff, in which case the students will get information about that first.) Can give them a circular template and then make overheads for use that day, or have them bring in a leaf or something to create their photo.
- Show an example of the paper then ask students to **predict** what will happen over the course of the activity.
- Go outside and have students set up their paper. On a sunny day, this will only need 2-5 minutes, but on a cloudy day, it will take 20. Have water ready to go for rinsing. While the students are exposing the paper, ask them what they think is going to happen, then after they have rinsed, ask them why they think that happened. (Notebook, handout)
- After everything has happened, ask students why the paper changed color 1) after exposure and 2) after rinsing it off in water. What was the difference between these

two processes? Why did some of the pigment wash off but not all of it? Why would some wash away and the rest wouldn't?

Head back inside to let them finish up. Go over concepts of 1) solar energy and how to capture it via reactions fueled by UV light (solar chemical, emerging tech; potential for water as fuel; artificial photosynthesis) and 2) pigment washes away because of solubility (see background above). At the end, ask kids to brainstorm 10 ways that photography concepts could be used in industry.

Day 2

Warm-up: 1) How do you think computer chips are made? 2) How do you develop a photograph?

Lesson: Photolithography

- Take out example silicon wafer, and then point out that it was made in the same way as their sun photograph. Have a diagram/presentation ready to go and walk them through it, then ask them to point out similarities between their activity and that of the photolithography.
- Go over deposition/lift-off using diagrams/presentations. Ask students to think of how they would get rid of the titanium and gold from everywhere EXCEPT for the original exposure from the photograph, then have them "report out."
- Tell them about practical applications, point out that they are used to create micromachines. They can then perform some research in order to find recent articles/actual technology that makes use of the micromachines.
- Go over the process of acetone dissolving the photoresist. Why would they need to use acetone? Why do some chemicals dissolve in water and some dissolve in acetone?

Assessment Procedures

-Notebook to take notes and to answer questions
-Brainstorming, warmups
-Create diagrams, photograph

Accommodations/Modifications

-Very hands on due to the photographs which allows kids to compare something they have done to something that is more abstract to them
-Diagrams and example of silicon wafer for students to see
-Brainstorming of ideas to get kids thinking about potential things they could do

Reproducible Materials

-Photographs
-Cleanroom contest
-Notebook with all of their notes and observations, warmups

Explorations and Extensions

Students could potentially have some sort of tour of BU and its facilities.
Have students explain the creation of some sort of modern technology—cell phones, digital cameras—using new terms.
This would lead well into renewable resources too, due to the use of solar energy/light as activation energy.

Lesson Development Resources

-Helen Fawcett, cleanroom pro
-Hands-on cleanroom experience
-http://www.cleanroom.byu.edu/processes.phtml ("basic interactive lithography tutorial")
-http://www.stevespanglerscience.com/product/sun-sensitive-paper

Reflections

Contact Information

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