Lesson Plan

Title
Screenprinting/photolithography and understanding MEMS production and their application

Primary Subject Area
Chemistry

Grade Level
High School (10)

Overview
Students will learn about microfabrication in 2 stages, ultimately leading to their understanding of how Micro-electromechanical machines (MEMS) are produced and what they are used for. In the first stage, students will actually screen print and learn about the reaction of light and emulsion to produce a print (mask). Once the students have seen this process on the macro (and relatively simple) scale, they will do photolithography (stage two of the lesson), which involves a slightly more technical understanding of chemistry and integrates many of the principles the students studied during the school year (reactions, light, solubility). Eventually, students will get to actually see some MEMS devices under a microscope (skyping with lab at BU) and learn about the commercial application of MEMS devices (used in the automotive, electronics, medical, communications, and defense fields). Students will understand that the screen printing and photolithography they did in the classroom mimics the process through which the MEMS devices are made (i.e. by actually doing the screen printing and photolithography, the students are able to visualize a process that is used to fabricate devices as small as the width of a piece of hair).

Approximate Duration
~5 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, t-shirt making), green technology (solar energy), engineering (photolithography, microfabrication), physics (MEMS devices)

Lesson Objectives
- Design and perform a simulation of how MEMS devices are produced using screen printing and photolithography
- Explain the chemical process (reactions, solubility, solar energy, reaction rate affected by light) of development
- Compare photographic processes (development, solubility) to photolithographic industrial processes (development, deposition, liftoff, solubility)

Lesson Materials and Resources
Screen printing:
- Mesh-wire board
- Emulsion
- Squeegees
- Incandescent light bulbs (150 Watt)
- Transparencies with desired image printed on it (using Fed-Ex/Kinkos)
- T-shirts
- T-shirt paint

Photolithography (taken from Liz Mundy’s Photolithography lesson plan):
- 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) or by light

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

MEMS devices:

- MEMS that Joel Bradford and I designed during our RET
- Skyping with BU labs to hopefully see the MEMS devices under high powered microscopes (get students to see something so microscale)

**Technology Tools and Materials**

- Cleanroom access, photos/diagrams/models
- Example silicon wafer and/or other item made in cleanroom
- Sun/bright light
- Skype into Dr. Bishop’s lab with class so class can see MEMS devices under a high powered microscope

**Background Information**

**Screen Printing**

The screen printing process begins by taking a wire/mesh frame and coating it with an emulsion. The emulsion sits under a bright (150-200W light bulb) until it has dried. Next, the transparency with the desired image will be placed on the screen and the bright light will shine upon it until the light has burned through the area around the image, thereby leaving behind only the desired image. Once the wire/mesh frame has the desired image burned onto it, it can be placed over a t-shirt or other material and coated with fabric paint, leaving the design on the material.

Screen printing is also used in the electronics industry to create high density flexible electronics.


**Photolithography (Taken from Liz Mundy’s “Photolithography” Lesson Plan):**

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) hexacyanoferrate (III), Fe[Fe(CN)₆]₃, 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) hexacyanoferriate(II), Fe[Fe₄(CN)₁₉]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.

**MEMS**

The MEMS fabrication process essentially uses the same process as the microelectronics industry as shown in Figure 25.

![MEMS Diagram]

Figure 25. Similarities between IC and MEMS microfabrication processes [3].

<table>
<thead>
<tr>
<th><strong>Table 1. Applications of MEMS [10].</strong></th>
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<tbody>
<tr>
<td><strong>Automotive</strong></td>
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<tr>
<td>Internal navigation sensors</td>
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<tr>
<td>Air conditioning compressor sensor</td>
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<tr>
<td>Brake force sensors &amp; suspension control accelerometers</td>
</tr>
<tr>
<td>Fuel level and vapour pressure sensors</td>
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<tr>
<td>Airbag sensors</td>
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<tr>
<td>&quot;Intelligent&quot; tyres</td>
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**Useful Vocabulary**

<table>
<thead>
<tr>
<th><strong>New Vocabulary Word</strong></th>
<th><strong>Meaning</strong></th>
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<tbody>
<tr>
<td><strong>Photolithography</strong></td>
<td>Photographic (use of light) printing using a metal plate with a completely smooth surface</td>
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<tr>
<td><strong>Microfabrication</strong></td>
<td>Fabrication (creation) of miniature structures on the micrometer scale</td>
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<tr>
<td>Exposure</td>
<td>Allowing a chemical (normally attached to a piece of paper) to react with light and form a new chemical</td>
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<td>---------------</td>
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<tr>
<td>Screen Printing</td>
<td>Printing technique used to transfer an image onto a substrate;</td>
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<tr>
<td>MEMS</td>
<td>Micro-electromechanical Systems; see table 1 for applications</td>
</tr>
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**Essential Questions to be answered; Grand Challenges**

- How does screen printing work?
- How does photography work?
- How does light affect chemical reactions?
- 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.
- MEMS are actually 3D devices, not 2D or “flat” like the t-shirts and photographs the class made.

**Lesson Procedures**

**Day 1**

- Warm-up: look at the t-shirts at the front of the room, how do you think the image got onto the t-shirt? Giant printer? Big marker? Stamps?
- Students will be told that they will be designing a t-shirt and the winner of the design competition (class vote) will have his/her design printed on a t-shirt for each chemistry student to receive. The T-shirt must involve something about chemistry and the school name/logo.
- Students will be asked to brainstorm ways that the winning design can be “etched” onto a t-shirt in small groups before learning about screen printing.
- Students will be asked to think about the reaction between the emulsion and the light and what makes it so that the light burns away at the areas around the images, but never the image itself.
- Students will be asked to explain how they think this process might be different or the same as photography (which will bridge into the next day’s topic).

**Day 2**

- Activity: Students actually screen print

**Day 3** (*Taken from Liz Mundy’s Photolithography lesson*)

- 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 today, 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 3 (Taken from Liz Mundy’s Photolithography lesson)

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?

Day 4

Skype day with BU, students will look at the MEMS devices under high powered microscope and finally see the application of the processes they studied on the previous days

### Assessment Procedures

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

### Accommodations/Modifications

- Screen printing and photolithography allows kids to visualize something that takes place on the micro-scale by letting them do it on the macro-scale
- 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
- Screen printing mesh boards
- Cleanroom/class contest
- Notebook with all of their notes and observations, warmups

### Explorations and Extensions

Students could visit BU, try designing MEMS using L-EDIT

### Lesson Development Resources

- Helen Fawcett, cleanroom pro
- Hands-on cleanroom experience
  - [http://www.cleanroom.byu.edu/processes.phtml](http://www.cleanroom.byu.edu/processes.phtml) (“basic interactive lithography tutorial”)

### Reflections

### Contact Information

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