Patterning by Light: the Engineering of Integrated Circuits
A module developed for hands-on learning

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Date of Creation: June, 2019

Publisher: Colorado School of Mines

How to Cite: K. Blagg, Y. Liu, W. Schenken, B. Moskal, M. Singh, C. Koh, R. T. Collins "Patterning by Light: the Engineering of Integrated Circuit a module developed for hands on learning." 2019. PDF file.

Funding information: This work was supported by NSF grants DMR 1810463 and DMR 1807583

Description: This document is a lesson plan for a short module covering:

(i) the concept of an integrated circuit and how it is patterned
(ii) how light is used to induce a chemical change and form a pattern
(iii) the size of integrated circuits and the concept of length scales

Colorado state science standards addressed by the module are included. The module is readily adapted for students in grades 1-12. It was originally drafted for presentation to children aged 7-13 at the Rocky Mountain Camp for Dyslexic Children. The planned activities are therefore hands-on and do not rely on reading or writing skills.

Science Standards Addressed: (from the Colorado Department of Education)

http://www2.cde.state.co.us/scripts/allstandards/costandards.asp?stid=7&stid2=0&glid2=0

Standard 1 - Physical Science

- High School
  - Outcome 3: Matter can change form through chemical or nuclear reactions abiding by the laws of conservation of mass and energy.
  - Outcome 6: When energy changes form, it is neither created nor destroyed; however, because some is necessarily lost as heat, the amount of energy available to do work decreases.
- 8th Grade
  - Outcome 2: There are different forms of energy, and those forms of energy can be changed from one form to another - but total energy is conserved.

    - Outcome 3: Distinguish between physical and chemical changes, noting that mass is conserved during any change.
- 4th Grade
    - Outcome 1: Energy comes in many forms such as light, heat, sound, magnetic, chemical, and electrical.

Objectives

- To understand what an integrated circuit is and how it is relevant to modern electronics
- To understand how light energy can be used to drive a chemical reaction and create a pattern
- To understand how patterning is used to create integrated circuits
- To appreciate the size and scale of integrated circuits and length scales in general (e.g. iphone screen vs. circuit vs. hair vs. molecules/bonds

Background

Integrated circuits have allowed many of the gadgets and tools you use on a daily basis including computers, tablets, smartphones, TVs, and much much more. What allows for our devices to increase in processing power and speed while decreasing in size is the use of photolithography (patterning with light) to pattern integrated circuits with very small complex features. This process is used on an industrial scale to create most modern circuit chips, displays, actuators and sensors. In research labs, photolithography processes are used to test new materials and devices. The photolithography patterning in use today can extend from very simple low cost patterning techniques, such as screen printing, to highly advanced and costly processes like electron-beam lithography.

The patterning done in this exercises uses UV light sensitive paper. It's a cyanotype printing process originally developed by an astronomer John Herschel in the mid 1800's. Herschel made many contributions to photography and the cyanotype process became the method for making architectural blue prints. The paper is treated with two iron containing compounds, ferric ammonium citrate (or tris(oxalato)ferrate), and potassium ferricyanide. Under illumination, the Fe in ferric ammonium citrate captures a citrate electron to move from Fe(III) to Fe(II). When placed in water, it then reacts with the potassium ferricyanide to form prussian blue which is not soluble in water. Those places exposed to light remain blue after the paper dries, but in the regions not exposed to light, the starting chemicals dissolve and the paper becomes white.

Safety

Activities will include the use of light sources including UV flashlights and UV laser pointers. Lights should never be pointed directly in your own or anyone else's eyes. Lights should be pointed down and away from the face when in use and kept off when not in use. Sunlight can also be used as the light source for patterning in this exercise. If sunlight is used, care should be taken to make sure solar exposure is limited to a short time or that participants are wearing an appropriate sun block.

Materials

Demo of Electronics
- Electronic circuit boards (dead electronics)

SEM Imaging of an Integrated Circuit
- Computer/projector set up
- Integrated for SEM or SEM images

Paper Patterning
- Photosensitive paper
- Transparencies
- Construction paper
- Scissors
- Markers
- UV flashlights
- UV laser pointer (optional)
- Water to develop paper
- Tray in which to do the development
- Stickers, leaves, or cut outs to make patterns
- Sample of different stages of photolithography

Introduction
Note: The following lesson plan encourages discussion and active participation. Class discussion questions are indicated by blue text.

- Show a completed patterned paper and ipad (or other electronic)
    - What does the paper example and this ipad have in common?
    - How many of you have an ipad, computer, phone?
    - How do they work?

Activity - Demo of Electronics

Preparation: Take apart any digital electronic device into its constituent components make sure that the screen, battery, and circuit board are visible. As much as possible remove any casing or plastic covering so that all components are visible.

Note: Throughout this module we have used an ipad as an example electronic circuit however any electronic device such as a computer, cell phone, TV, or gaming console will work and questions can be adjusted accordingly.

Activity: Open up the ipad to show the insides and pass around any parts.

- Discussion of electronic components:
    - What part do we need for a computer, smartphone, or ipad to work?
        - Highlighting screen, battery, memory, processor, sensors, cooling units
- Does anyone know how a screen works?
    - Using a flashlight, shine a light on the screen. If the angle is correct students should be able to see a reflected rainbow which is made up of small dots. These are the individual pixels which make up the screen.
    - In discussion it should be highlighted that the screen is made up of smaller components called pixels that form an image on the screen. Note that these pixels are incredibly small.
- Where are these parts in the electronic device?
    - See if the students are able to indicate where these components are on the disassembled device. They should be able to point out the screen, battery, some sensors, and the cooling unit. While it is difficult to point directly to the memory and processor students should understand that both components are on the circuit board.
    - Note that most of the space is taken up by the battery and screen. The 'brain' of the ipad is incredibly small.
- Describe what an integrated circuit is:
    - Similar to a screen in which the screen is made up of thousands of tiny pixels the processor and memory components of the ipad are made up of smaller parts called integrated circuits.
    - Do you know any circuit elements?
        - Students should know about wires and resistors. Older students may be able to indicate other components such as capacitors, transistors, and inductors. For students who do not have any circuits knowledge highlight that integrated circuits are made up of lots of little electrical components and wiring.
        - All of these circuit elements are patterned on to an integrated circuit so that the electronics can do the various tasks required: storing memory, reading memory, connecting to sensors, processing inputs.
    - How many are in your phones, computers, and ipads? How large must they be?
        - Highlight that there are thousands of these circuits on just one circuit board. To do this the integrated circuits must be very small.
        - Students should begin to get a sense of scale: ipad, circuit board, processor/memory ('the brain'), integrated circuit.

<u>Activity - SEM imaging of an integrated circuit</u>

Note: This activity uses an electron microscope. If an electron microscope is not available the activity can be completed using prepared electron microscope images of a hair and integrate circuit and various magnifications. Questions can be modified to images or an alternative microscope setup.

Preparation: Prepare and integrated circuit for the SEM, this can be from any electronics device. It is easier to access an integrated circuit in an older device. Place a hair on the integrated circuit. Load the sample into the SEM.

Activity:

- Beginning with the optical microscope show the integrated circuit.
    - With an optical microscope we are able to zoom in pretty far, much farther than you can see with your eyes, but we still can see things that are really small. To see something really small, like the surface of your hair we need to use an electron microscope.
    - We can see the entire chip and it is a few millimeters in size
- Using the electron microscope, zoom in on the hair
    - You should be able to see features on a single hair.
    - How big is the hair?
        - Note to students that we have a scale bar and can see that the hair is about 50 microns in diameter.
    - The hair is used as a reference to help students understand how small the integrated circuit and patterns on the circuit are. Other references such as dust can also be used as reference.
- Now, move from the hair to the IC. Using the remote control, move around the chip, zoom in and out, etc.
    - Students can decide what they want to look at. Where we should zoom in etc.
    - How big is the IC? How big are the patterns?
        - Students should understand that a single integrated circuit is made up of layers of patterns. These patterns make up the circuit elements that make the device work.
        - Highlight that the patterns on the circuit are much smaller than a human hair.
- Lead into lithography (patterning with light)
    - How can we make patterns that small?
        - Can we use a pen and draw patterns?
        - How much bigger is a pen than the patterning on the circuit?
    - There are thousands of these in one device. How can we make them quickly?
    - Since we cannot use a pen, we have to find something else to make the patterns with. Instead of a pen we use light in a process called photolithography.

<u>Activity - Paper Patterning</u>

Introduction:

- Explain the paper

    - Here we have paper that works much in the same way that the chemicals used in photolithography work. When the paper is exposed to light the paper undergoes a chemical change. It's white when exposed, but when rinsed, becomes blue again with the blue regions becoming white.
    - If we want to make patterns on the paper what would we need to do?
        - We need to create a mask that would cover the parts we want to stay blue and show the part we want to be white.

Activity:

- Have each student make a mask by making a design on a transparency. This can be done by:
    - Cut and paste shapes/designs
    - Stick on shaped stickers and cutouts
    - Stick on leaves/flowers
- Close any windows to minimize the sunlight that gets through
    - Why do we need to close the windows? What happens if we don't?
- Place the photosensitive paper under the transparency with the design
- Hold the UV flashlight over the paper for 2 minutes
- Rinse the paper in water and leave to dry
    - Students should see their pattern on the paper.

Post Discussion:

- Explain basic idea of lithography with examples to pass around if avalible:
    - Chemical is spun onto chips that reacts to the energy in light. That is the blue coating on the paper.
    - Using a mask similar to the ones you made, but with much smaller designs some parts of the chemical are covered and other exposed to UV light. This UV light causes a chemical reaction just like the light caused a chemical reaction on the paper.
    - After developing (placing your paper in water) the places that have been exposed to light dissolve leaving the pattern in the chip.

Optional Addition - Alignment:

- In the circuit that we saw there were a lot of layers. These are different materials and patterns all stacked on top of one another. To make the circuit work the patterns have to be stacked on each other in exactly the correct place. The process of lining up one layer with the previous on is called alignment.
    - What would we need to do if we want to create multiple layers of design?
        - We would need to make two different masks so that one pattern lines up with another. This way we can line up the previous pattern with a new pattern.
        - This is used in the patterning of IC to create the different layers we see on the chip.
- Can you mask a mask that requires two different exposures?

- Repeat the process for exposure, but do it in two levels
    - How can you align your two patterns?

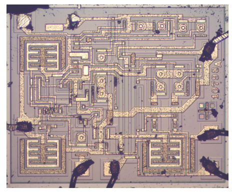
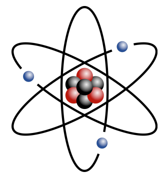
Optional Activity - Electron Beam Lithography

Introduction:

- Are there any other ways we can think of patterning with light?
- What if we had a laser pointer instead of a flashlight?
    - With a laser pointer we can write like we do with a pen but with light.
    - The students can use a move a UV laser pointers slowly over the surface of the photosensitive paper this is another way of patterning.
- This is a method similar to an experimental technique called e-beam lithography. In this case instead of using a mask and a lamp we can use an electron beam to write any pattern we wish.
- What would be the pros and cons of this method?
    - What if you needed to pattern 1,000 chips?

Assessment

Place these objects in order of size:


(a) human hair (b) wiring in electronic circuit (c) atom (d) cell phone

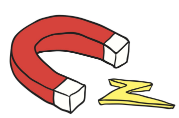
Which of the following rely on patterning to function:




(a) television (b) telephone (c) car (d) refrigerator

Which of the following was used to induce a chemical reaction in this activity:






(a) light (b) heat (c) magnet (d) hammer

In your journal write/draw or as a discussion what does your patterned blue and white paper and an integrated circuit have in common.