Unit V Microsystems Technology

A major portion of the information for this unit was obtained from "Beyond 2000 Micromachines and Nanotechnology" by David Darling.

On the cutting edge…
Scientists at the University of South Florida's Center for Ocean Technology are the explorers of today discovering new worlds at the micro environmental level. Using new technology developed from studying nature, they have created affordable microsensors that can be used to make chemical, biological, and physical measurements in the ocean. In addition, they are testing sensors that may be used in human fluids such as blood, to make disease fighting in the future a less invasive procedure.

Introduction to Microsystems

Lesson Objectives: Students will be able to do the following:

- Name the inventors of the first miniature machines
- Describe a microchip
- Name two reasons why developing micromachines is important

Key concepts: mechanical, electronic, diode, triode, transistor, conductor, insulator, semiconductor, dopant, microchip, micromachine

History of Micromachines

The first miniature machines were actually elaborate **mechanical** toys produced by the Chinese about 200 B.C. These toys relied on the simple principles of physics that dealt with the movement of small parts. Through the centuries people began to realize that **mechanization** could also be used for practical purposes. For instance prior to the 1500's, clocks were driven by huge weights that made them extremely large and bulky. A German locksmith using the Chinese technology developed a **mainspring** to replace the huge weights. The mainspring was a coil of wire that allowed the gears to move as it unwound. By replacing the weights with this very small lightweight item, the clock became portable, which led to the watches that we have today. From these beginnings, there was a proliferation of inventions on a small scale. Miniaturization allowed items to be used in a wider variety of ways. Eventually complex machines that fit into very small spaces were designed to efficiently perform complicated tasks.

During this transition period inventors were able to refine many of the problems associated with simple mechanical devices. At the same time, other researchers were discovering **electricity** and its properties. The discovery of the **electron** by J.J. Thomson in the 1890's led to the invention of the diode in the 1900's by John Fleming. This signified the beginning of the **electronic** age.

The **diode** consists of two pieces of metal known as **electrodes** inside a **vacuum tube.** As the first electrode is heated, it releases a flow of electrons to the second electrode. This flow of electrons only goes in one direction, but it travels at different rates depending on the **voltage** of the second electrode. The diode was an important discovery, because it created a way to regulate the flow of electricity. Vacuum diodes were used in televisions and radios to convert waves into signals that could be transmitted long distances. Today they have been replaced by solid state components.

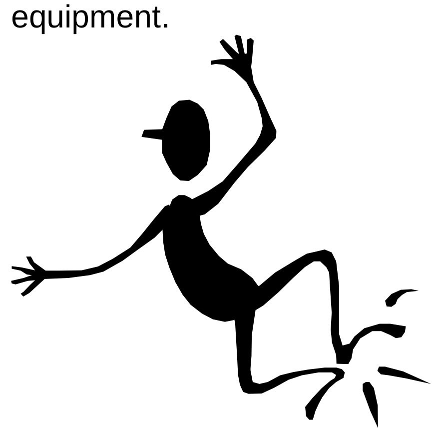
Commonly in scientific experimentation one person will build upon the work of another to make a new product or a more efficient one. This was the case with the diode. Another scientist, Lee de Forest, modified the diode with the addition of a third electrode to produce the **triode.** Scientists discovered that triodes caused big changes in **current** from small changes in voltage. This allowed very weak signals to be amplified, making them useful as components in record players and televisions. Scientists building the first electronic computers also used triodes as the switching devices that represented information. They could turn them "on" when a current ran through them and turn them "off " when the current stopped. Since triodes were quite large, the first computers were big and bulky. The triodes also overheated easily causing the computers to breakdown frequently.

In 1947 American scientists working at Bell Laboratories were trying to solve problems associated with sound **transmission** and **amplification**. William Shockley, John Bardeen, and Walter Brittian, turned to the work of earlier scientists and began to experiment with the properties of **crystals**. They discovered that crystals had two distinct areas. Some areas acted as **conductors** and allowed electrons to flow across the surface. Other areas acted as **insulators** and did not allow electron flow. The scientists also discovered that these areas could reverse their properties depending on the electric current sent through the crystal. They called these crystals **semiconductors.**

They discovered that when wires were attached to germanium crystals it created an electron flow that would amplify sound just the way the triode did. They called this invention the **transistor**. This item worked like a triode but was much smaller, solid rather than encased in a vacuum tube, and did not require heat to regulate the electron flow.

With further crystal experimentation, scientists discovered that **silicon** was a better semiconductor. They discovered that the insulator and conductor properties of various areas were dependent on the amount of impurities present in the crystal. They were able to isolate and recreate these impurities or **dopants.** Further experimentation showed that the more dopants present, the greater the electron flow. This led to the development of silicon based transistors. In the 1950's transistors using silicon as a semiconductor began to replace triodes in computers. This allowed computers to become smaller, more efficient, and more reliable. Once again, scientists trying to solve one problem actually solved another and were able to apply their discovery to a broad range of applications.

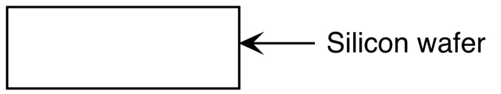
In the 1960's, scientists developed a process to manufacture inexpensive transistors to help lower the cost of computers. This process involved creating many transistors simultaneously on a single crystal of silicon. This single chip of silicon became known as the **integrated circuit**. As the transistors and components on a chip became microscopic in size, they were called **microchips**. Now millions of components can be contained on one chip. These chips are used in computers and all types of other electronic equipment.



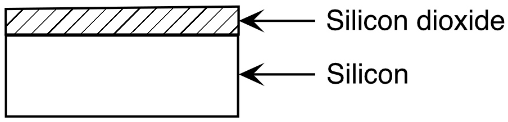
How Microchips are Made

Microchips are made using a process that builds up several layers of chemically distinct materials and then removes them in a stepwise process leaving the circuit **etched** on the top of the silicon crystal. By repeating the process, layers of circuits with complex components can be created on one silicon wafer. These circuits are the pathways through which electronic information is sent. (See the following diagram for details.)

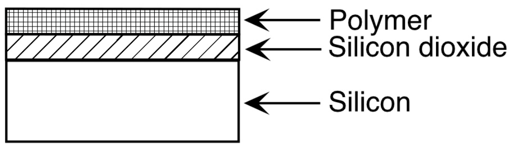
Microchip Fabrication



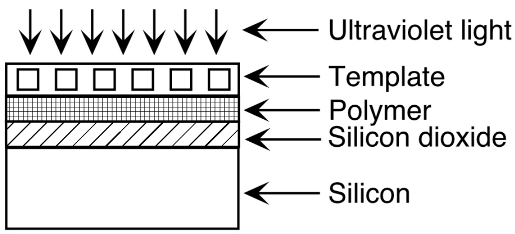
1) Silicon wafer is heated to a high temperature.



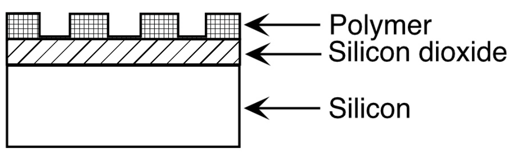
2) A silicon dioxide layer is produced while heating. Silicon dioxide is an insulator.



3) A light sensitive polymer is added.

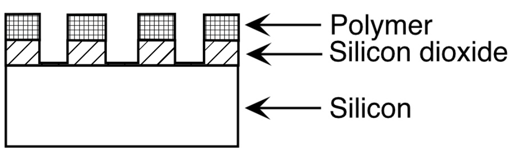


4) Ultraviolet light is shown through the template containing the circuit details. The exposed polymer areas become easier to dissolve.

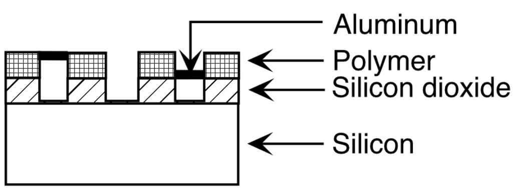


5) A chemical dissolves the polymer coating where it has been exposed to light.

6) The remaining polymer is baked to make it acid resistant.



7) The whole wafer is bathed in acid and the unprotected silicon dioxide is eaten away.



8) Dopants are added to change conductivity in some areas.

9) Aluminium is added to provide electrical connections.

10) Repeating this process creates layers of circuits.

Now that scientists can make microscopic electronic components, they are designing **micromachines** called **Microelectromechanical Systems (MEMS).**

Activity: Build an Edible Microchip

By
Cyndy Leard

Scientists have refined the building of microchips using a layering technique to etch and build channels that become the integrated circuits. In this activity you will recreate this process using edible materials.

Objective: Students will be able to describe the steps involved in microchip manufacture by creating an edible microchip.

Note to Teachers: This may also be done as a demonstration requiring fewer supplies.

Materials:
- Cake-one-fourth of a cake for every group of students
- Frosting-one batch per cake (This would be enough for four groups.)
- Food Coloring-blue and yellow
- Cookie sugars-any color
- Cookie sprinkles-chocolate or multicolored (Chocolate chips could be substituted for the sprinkles.)
- Shoe string licorice
- Fruit Roll-ups-two per group
- Cooking oil or nonstick spray
- Wax paper
- Paper towels
- Plastic sheets to make stencils (4 ½ inch by 3 inch piece per group)
- Scissors-for cutting stencil patterns
- Plate-to hold cake for each group
- Plastic gloves or small bags to be used as gloves
- Toothpicks

Prior Set-Up:
- Bake cakes in rectangular pans.
- Make frosting-the recipe for one batch follows:

1 cup of Crisco	Dash salt
3 tbsp ice water	1 tsp. vanilla
	1 lb. Confectioners' sugar

Cream first four ingredients then add sugar ¼ at a time. Mix well on low speed. Then beat 3 to 5 minutes with an electric mixer on low to medium speed. Shelf life is one week.
- Cutting plastic stencils and fruit roll-ups
  Plastic stencils and fruit rolls-ups need to be cut in the same design. A two-

part design works best. (See diagram 1.) Cut a 3 ½ by 4 inch plastic sheet for each group. This should be approximately ½ of the size of the piece of cake each group will receive. Cut the design into the plastic sheet. Students will use the outer section of the sheet. Next unroll two fruit roll-ups and put wax paper on the exposed sides. This keeps the fruit roll-up from tearing while it is being cut. Cold fruit roll-ups also hold their shape better than warm ones. Cut each fruit roll-up using the plastic stencil as a pattern. You should have two identical fruit roll-ups when you are finished. Students will need both sections of the fruit roll-ups for their microchip.
Note: More advanced students can prepare the stencils and fruit roll-ups. Fruit roll-ups may also be cut into ½ inch strips instead of the exact design for ease of preparation, however the results will not be as exact.

Procedure:
1. Divide students into groups
2. Describe the steps involved in building a microchip (See attached instructions.)
3. Give each group one fourth of a cake, two precut fruit roll ups, one precut stencil (outer section only), food coloring, cookie sugars, cookie sprinkles, licorice, toothpicks, and plastic gloves.
4. Have students wear plastic gloves when they are working with the food materials. (**Note:** Fruit roll-ups are difficult to manipulate while using gloves, so use your discretion.)
5. Have students follow the microchip construction steps to create an edible microchip. (This can be a teacher directed activity or groups can work independently.)
6. After all microchips are completed, discuss the process used to build the microchip. Compare and contrast this process to the actual process. Discuss the difficulty involved in creating accurate circuits at microscopic levels. (Students may eat their microchips after the discussion.)

Microchip Construction:
1. The silicon wafer (cake) is the base for the circuit.
   Give each student group ¼ of a cake on a plate.
2. When the wafer (cake) is heated, a film of silicon dioxide (fruit roll ups) covers the wafer (cake).
   Have students lay the two precut fruit roll ups across their cake top leaving the cut ends extended over the side of the cake. (See Diagram 2. Note: Students should be using both sections from the two fruit roll-ups, so the entire cake top is covered.)
3. Next a polymer layer (frosting) is applied over the silicon dioxide layer (fruit roll ups).
   Have students completely cover the fruit roll up layer with ½ inch of frosting. (See Diagram 3.) Do not frost the sides of the cake. Allow the cut ends of the foot roll-ups to be exposed.

4. Next a mask containing the circuit details (plastic stencil) is placed over the polymer (frosting).
Have students coat their stencil with nonstick cooking spray or cooking oil and wipe off the excess. Then have students lay their mask (plastic stencil) on top of the frosting layer over ½ of the cake. Be sure to orient it correctly. (See Diagram 4.)
5. As light is shown through the mask (plastic stencil) it creates the circuit pattern on the polymer (frosting).
Have students use small amounts of yellow food coloring to color the exposed areas. (They may mix it in using toothpicks.)
6. The mask (stencil) is then moved to the next area, and the process is repeated until the polymer (frosting) is covered with the pattern.
Have students move the template to other side of cake and continue coloring until the cake top is completely covered with the pattern, and exposed areas are colored.
Remind students to orient their pattern the same way each time, so it will match the pattern of the fruit roll-ups below. **The colored areas are the parts of the polymer that have not been exposed to light.**
7. Next a chemical called a developer (pressing motion) removes the polymer in the areas exposed to light.
Have students push their stencil into the frosting layer creating elevated areas where the holes are located.
8. The remaining polymer (yellow frosting) is baked (turned green) to make it chemically resistant to acid.
Have students add small amounts of blue food coloring to the yellow elevated areas and mix to make green. Then have students remove the stencil by pulling it up slowly being careful not to disturb the elevated areas. Have students repeat steps 7and 8 for the entire cake top.
9. The wafer is then bathed in acid (cookie sugars).
Have students lightly sprinkle cookie sugars over the entire cake top.
10. The acid attacks the polymer areas that have been exposed (indented areas) and dissolves away the layers including the silicon dioxide layer (fruit roll-ups)
Have students pull up the outer edges of the fruit roll ups.
(See Diagram 5.) Note: This will remove all of the indented areas leaving only the elevated areas and exposed cake top.
11. Dopants or impurities (cookie sprinkles or chocolate chips) are placed throughout the pattern to change the conductivity in certain areas.
Have students put cookie sprinkles in various places in the pattern on their cake top.
12. Aluminum (shoe string licorice) is also placed throughout the circuitry to act as a pathway between the components.
Have students put short pieces of licorice in various places throughout the pattern on their cake top.

13. Have students compare their microchip to an actual chip. Also remind students that the silicon base is a semiconductor, so it can act as an insulator or conductor depending on the amount and placement of the dopants in the circuit. The aluminum connections will also allow the electrons to flow through various parts of the circuit.

Possible Extensions:

1. Students decide on other materials that could be used to make microchips.
2. Students try to create accurate smaller versions of a completed microchip.

Edible Microchip Construction

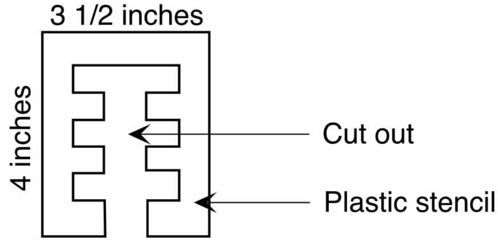


Diagram 1

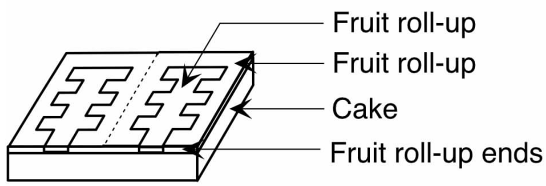


Diagram 2

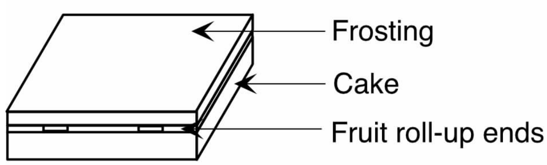


Diagram 3

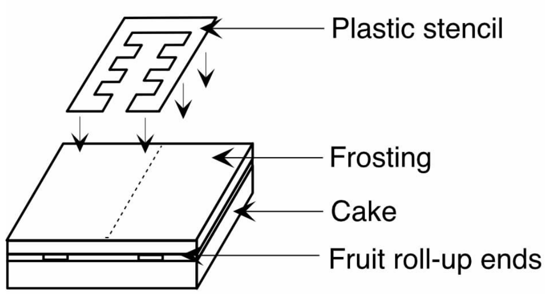


Diagram 4

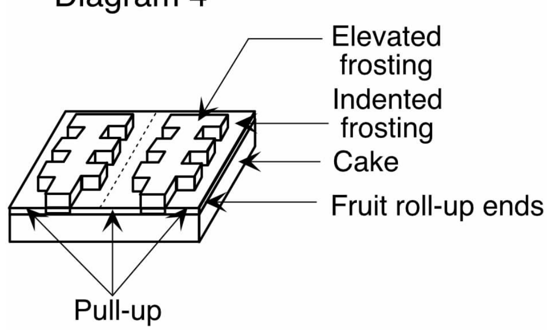


Diagram 5

Student Information: Mechanical Toys

Throughout history people have been curious about the world around them. They have asked questions and searched for answers to everyday happenings. Taking what they have learned, they discovered how forces such as **gravity** and **friction** worked. They used this information to create new things. Some of the items created were **mechanical** toys.

Mechanical items have moving parts. The first mechanical toys relied on physical forces to move. They had wind up springs or pendulums that would start the movement. For instance, over two hundred years ago, a Swiss clockmaker used what he knew about wheels and springs to make a doll that would move a quill pen as if it were writing.

Through time, mechanical also came to mean items that not only had moving parts but electrical parts as well. Today we have all kinds of **animated** figures. We find them in stores during the holidays dancing, moving, and lighting up their eyes. These devices have moving parts driven by electrical energy. Many of them use batteries to supply this energy, while others need to be plugged in to an electrical outlet.

Now scientists use **microchip** technology to make dolls that laugh and cry and robotic dogs that do tricks on command. These **electronic** devices rely on tiny **sensors** made from **microscopic** parts just the way microchips are made.