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Cookie Wafer Fabrication Activity Guide

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Cookie wafer fabrication

Grade level: 6-10	Group size:
Time: 30-45 minutes	Presenters: 1-2

Objectives

- Students will learn about the conductivity of materials and that semiconductor materials like silicon can be altered to be more conductive and can be utilized in very small and complex electrical circuits.
- Students will step through the semiconductor fabrication process from sand to computer chip and will gain a basic understanding of the processes involved in semiconductor fabrication.

Standards

This lesson aligns with the following Next Generation Science Standards (NGSS):

Physical Science (PS)

- PS1.A: Structure and Properties of Matter
  Semiconductor fabrication involves manipulating materials at the atomic level, which ties directly to understanding matter and its properties.
- PS3.C: Relationship Between Energy and Forces
  Fabrication processes often involve thermal, chemical, and electrical energy transformations.

Engineering, Technology, and Applications of Science (ETS)

- ETS1.A: Defining and Delimiting Engineering Problems
  Students can explore challenges in chip design and fabrication.
- ETS1.B: Developing Possible Solutions
  Lessons can include prototyping or modeling fabrication steps.
- ETS2.A: Interdependence of Science, Engineering, and Technology
  Semiconductor fabrication is a prime example of how scientific principles drive technological innovation

Fabrication Process Cookie Wafer Activity

Materials:

- Sugar cookies with colored frosting (pink used in presentation) - 1 per student
- 3-4 Tbsp scoop of second color frosting (white used in presentation) – One 11.2oz can container will provide enough frosting for 8-10 students
- Colored Sprinkles – 1 per group
- Plates - 1 per student
- Knives - 1 per student
- Napkins - 1 per student
- X paper or cardboard pattern - 1 per student (see dimensions and instructions at the end of this Activity Guide)
- Fabrication handout - 1 per student

Process:

As you walk students through this simulation of the wafer fabrication process, you can refer to the Cookie Wafer Fabrication handout and utilize the Cookie Wafer Fabrication presentation.

It is very important to have very **clean wafers** when the fabrication process starts. When Micron receives bare silicon wafers from a supplier, they are inspected, split into boxes of up to 25 wafers, and sent to the first fabrication processing step which is a **clean**. These wafer substrates are made out of silicon, a semiconductor material. Silicon is the semiconductor material of choice for the substrate because it is very abundant in nature and relatively inexpensive. Silicon also has a very high melting point which is needed to support high temperatures during the fabrication process. Semiconductors like silicon are materials that can have their electrical properties fine tuned to be a good conductor under certain conditions or to behave as an insulator under other conditions. With insulators and conductors and different patterns, we can create electrical circuits that perform certain functions like storing binary data.

For the fabrication process, the wafer will go through hundreds of process steps. This lesson covers the basics of some of the key processes. Cleaning the wafer is the first step because any contamination on the wafer can lead to electrical circuit defectivity.

For the Cookie Wafer Fabrication activity we are not going to clean the cookie wafer with any product so the clean process will only be mentioned. Note: some teachers may choose to provide cookies that already have a first layer of frosting.

Picture showing a sugar cookie which represents the bare silicon wafer.

DIFFUSION

Diffusion is the first process step for the wafers. The wafers are placed into a furnace that can be as hot as 1000 degrees Celsius. (Remember that boiling water temperature is 100 degrees Celsius. So, this is definitely **HOT!**) The furnace allows us to either grow or deposit materials onto the wafer. We will be building our semiconductor components and circuits on the top part of the wafer. Any material that is grown on the bottom portion of the wafer will eventually be removed. In the presentation and handout, we do not show the films grown or deposited on the back of the wafer.

Diffusion grows or deposits a film of silicon dioxide (the composition is SiO_2) and it is commonly referred as “oxide”. The oxide layer (pink frosting) acts like armor to protect the wafer.

1. Start with a cookie with colored frosting. The cookie represents a bare silicon wafer and the colored frosting represents the oxide from the **Diffusion** step. Alternatively, student can be given a sugar cookie with no frosting, and they can be guided to spread the frosting as evenly as possible using a knife.

Picture after step 1 is completed.

Photolithography COAT & BAKE

After diffusion, wafers enter the first step of the **Photolithography** area: Coat & Bake.

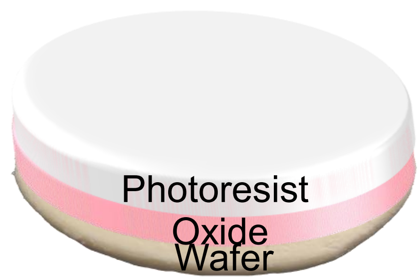
In the Coat step, a layer of photoresist is applied on the topside of the wafer. The photoresist acts like the film in a camera and allows us to place a pattern onto the wafer. The thickness of the resist is based on the viscosity of the mixture and the RPM (revolutions per minute) the wafer is spinning when the photoresist is applied. Photoresist is a viscous film.

In the Bake step, the photoresist is baked (heated) so it becomes hardened.

Due to the light sensitive processes done in the Photolithography area, everything is done under special lighting in this area of the fab. It is easy to identify the Photolithography area in a fab because the lighting is yellow. This yellow light used in the Photolithography area does not contain all of the frequencies of light that regular white light has. Regular white light could affect the properties of some types of photoresist. This is similar to needing special lighting in a dark room when processing photos.

Notice the yellow light in the Photolithography area of the fab

2. In the **Photolithography Coat & Bake** step, add the photoresist by applying a layer of white frosting to the top of the oxide (it can be any colored frosting, but ensure it is a different color than the first layer of frosting).



Schematic after step 2 is completed.

A real picture after step 2 was completed.

Note: In the picture, the white frosting should be more uniform, as flat as possible, as non-uniform photoresist can cause defectivity on the wafer. Also, there should not be any pink frosting visible from top-down view. Encourage participants to make their cookie look like the schematic as much as possible.

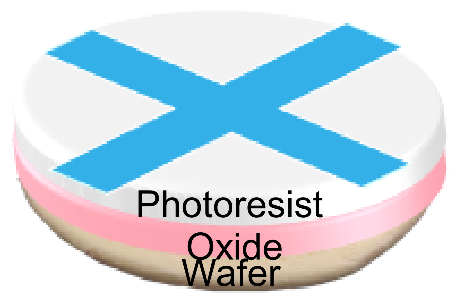
Photolithography ALIGN & EXPOSE

During the Align & Expose step, we put a pattern on the wafer. Shining ultraviolet light through a reticle (also called mask) transfers the pattern from the reticle into the photoresist. The simplest reticles are made of glass (transparent to UV light) and have a pattern etched in chrome (chrome is dark and UV light does not go through it) hence chrome is a dark pattern. The reticle is placed over the wafer with a light shining through a lens system. The lens system is between the reticle and the wafer. The lens system shrinks the reticle pattern down and exposes the shrunken pattern on the photoresist on the wafer. Most photolithography tools shrink the pattern 4 or 5 times smaller. We call it a lens system because there are really several lenses (not just one) in the path of the light between the reticle and the wafer.

- Wherever there is the darkened pattern in the reticle, the light is prevented form going through to the reticle.
- Wherever there is glass in the reticle, the light shines through, passes through the lens system and then hits the wafer.

The areas of the photoresist that light hits are altered. These portions of the photoresist exposed to light are easy to remove in the Develop step that follows. Once the pattern has been imprinted on the photoresist in the whole wafer, the wafer moves to the next step. The align & expose step is comparable to taking a picture or getting a sunburn and having a pattern left on your skin.

3. For the **Photolithography Align & Expose** step, gently place a cut out "X" pattern on the top of the cookie. Note: you can choose a different pattern if preferred. Also important to note: in current photolithography processes the reticle does not touch the photoresist.



Schematic after step 3 is completed. "X" pattern represents reticle or mask.

Note: in this picture the white frosting should be more uniform, as flat as possible, as non-uniform photoresist can cause defectivity on the wafer. Also, there should not be any pink frosting visible from top-down view.

A real picture after step 3 was completed.

Photolithography DEVELOP

In the Develop step, a chemical solution is placed over the wafer and the portions of the photoresist that were exposed to light are removed/washed away.

After Develop, photoresist that was exposed to Ultraviolet light was removed (developed away) and now there is some diffusion material (oxide) no longer protected by resist.

4. For the **Photolithography Develop** step, scrape away only the white frosting that you can see (not covered by the "X" pattern). Be careful not to scrape the "oxide" pink frosting. After scraping away the white frosting carefully peel away the X pattern. At this point, you should still have all of the pink frosting and an X pattern of white frosting on top, as shown in the picture.

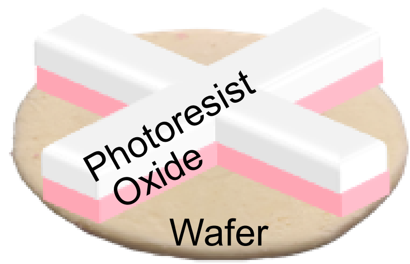
Schematic after step 4 is completed.

A real picture after step 4 was completed. It can be messy! Encourage participants to make their cookie look like the schematic as much as possible.

ETCH

The Etch area uses either gases/plasma (dry etch) or liquid chemicals (wet etch) to remove the material that is not protected by photoresist. Once the unwanted materials are removed, we are left with some exposed wafer and also some oxide film that is still being protected by photoresist.

5. For the **Etch** step, remove the pink frosting that is not covered by the white patterned X frosting (this represents the etch or removing of oxide not protected by photoresist).



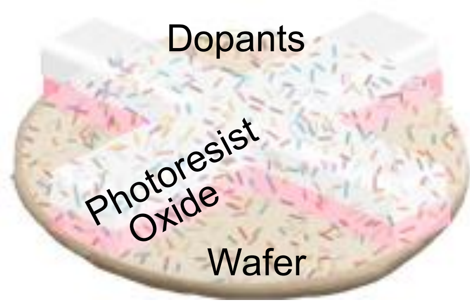
Schematic after step 5 is completed.

A real picture after step 5 was completed. Note that this picture still shows some pink frosting in unprotected areas. Encourage participants to make their cookie look like the schematic as much as possible.

IMPLANT

During the Implant step, specific ions called dopants are implanted into the areas of the silicon wafer that are not protected by photoresist. The regions of the silicon that now have these dopants implanted have different electrical properties than other regions of the wafer. The most common ions used as dopants are Phosphorous, Arsenic and Boron. During the Implant process, ions are accelerated into the wafer. Engineers can control how deep into the silicon the dopants go by choosing a specific energy: the higher the energy, the deeper the dopant penetrates. The photoresist region is also being bombarded with implant dopant ions so photolithography engineers need to calculate the thickness of the photoresist film so it can absorb all these dopants and prevent the dopants from penetrating into the films the photoresist needs to protect.

6. For the **Implant** step, apply sprinkles all over the cookie. Note: In the real implant process your sprinkles would be accelerated and slammed into the cookie, penetrating into the cookie. For our activity though the sprinkles will only be deposited on the surface of the cookie.



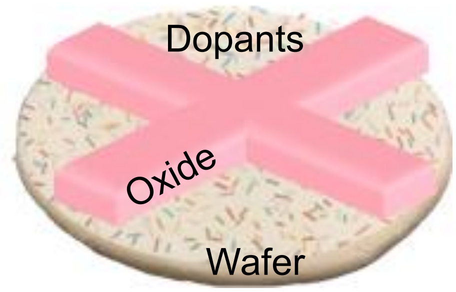
Schematic after step 6 is completed.

A real picture after step 6 was completed.

Strip photoresist

At the Strip photoresist step the remaining photoresist is removed. This is usually done with an Etch process.

7. For the **Strip photoresist** step, remove all of the white frosting. You are left with the entire wafer (sugar cookie), areas of the wafer that have dopants (sprinkles), and a pattern of oxide (pink frosting).



Schematic after step 7 is completed.

A real picture after step 7 was completed. This picture still shows some white frosting. Encourage participants to remove all white frosting representing the photoresist.

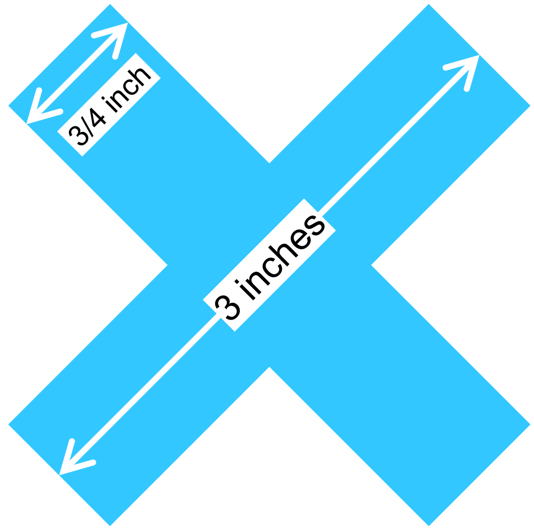
Continuing the fabrication process

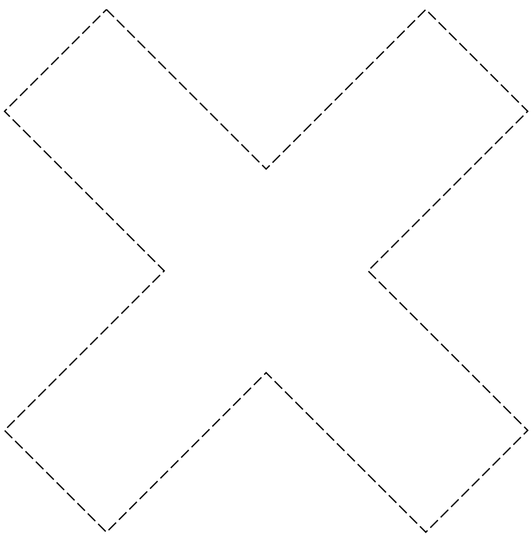
In the Cookie Wafer Fabrication activity we showed 7 process steps. To put things in perspective, in order to fabricate a state-of-the-art memory semiconductor chip a wafer will go through a sequence of about a thousand process steps over the course of more than a month!

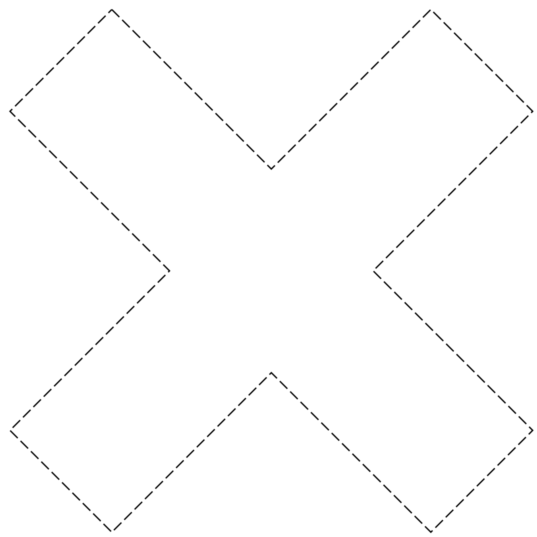
How to make the "X" reticles or masks

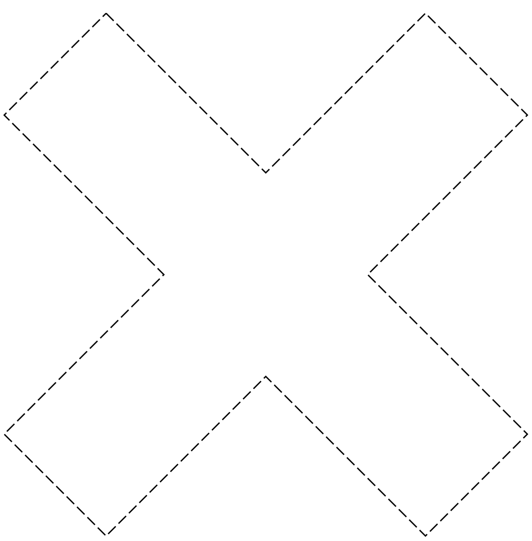
Material:
Colored Cardstock Paper

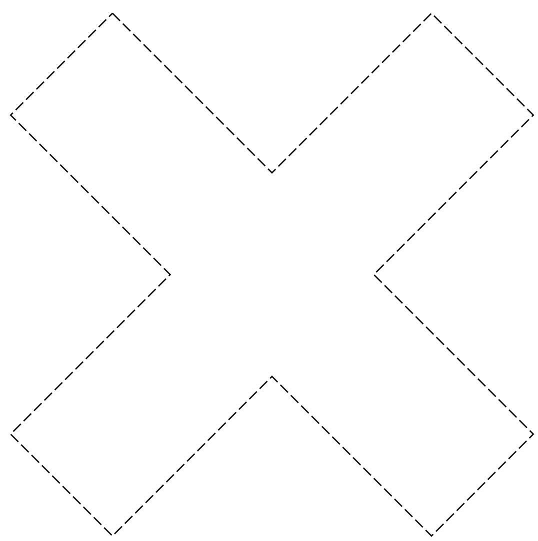
Size specifications:
3 inches wide and tall
Each strip is ¾ inches wide











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