An Origami Crystal Activity
Instructor Guide

Notes to Instructor

An Origami Crystal is an activity for the Crystallography Learning Module. This activity will help the participants to "see" different crystal planes as defined by Miller Indices. Twelve (12) origami templates are contained in the SCME Crystallography Kit available through http://scme-nm.org.

The Crystallography Learning Module consists of the following:

- Knowledge Probe (KP) Prequiz
- Crystallography Overview for MEMS PK
- Growing Crystals – Hot Ice Activity
- The Miller Index Activity
- Breaking Wafers - Activity
- **An Origami Crystal - Activity**
- Crystallography Assessment

This companion Instructor Guide (IG) contains all of the information in the PG as well as answers to the Post-Activity questions.

Description and Estimated Time to Complete

In this activity you will use a template to construct a representation of a silicon crystal. The final structure will actually be a rhombicuboctahedron, one of 13 Archimedean solids or a convex polyhedral. Certain faces of the template are marked with specific plane notations from Miller Index. Once the polyhedral is constructed, the markings will illustrate the crystal plane of each face of the polyhedral.

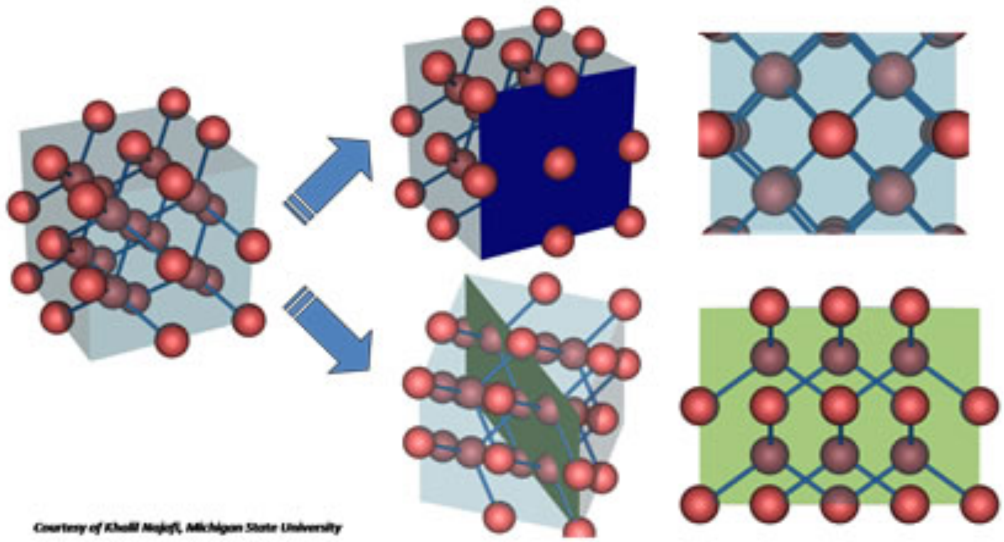
You will use the Japanese art of origami to construct this solid from a template.

Estimated Time to Complete
Allow at least one hour to complete this activity.

Introduction

Crystals are defined by a regular, well-ordered atomic lattice structure. A lattice consists of stacked planes of atoms. The bonds between the atoms are typically very strong.

Silicon crystal is widely used in micro and nanotechnologies. The orientation of the silicon crystal denotes which crystal plane is exposed on the wafer surface. *(Refer to the graphic below in the following discussion).* The left most image shows the silicon crystal structure, also known as face-centered cubic or diamond cubic. It is the same structure carbon forms in a diamond. The middle images highlight two different planes within this structure. Think of looking at the same crystal from two different directions. The images on the right are what you would see looking at the face of each plane. Same crystal, same distance between unit cells, and same orientation of unit cells. However, looking at different planes, presents a different picture.



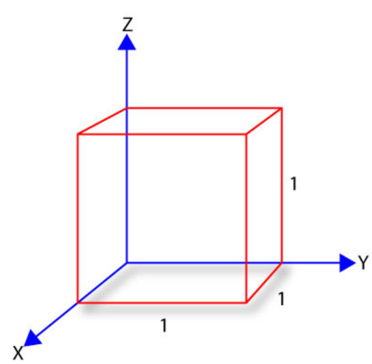
Silicon Crystal Planes
[Graphic courtesy of Khalil Najafi, University of Michigan]

The Miller index is a roadmap or directional compass for identifying the crystal planes and directions within crystals. Miller indices are three digit notations that indicate planes and direction within a crystal. These notations are based on the Cartesian coordinate system of x, y, and z. The Cartesian coordinate system is illustrated using the three vectors (axes) x, y, and z.

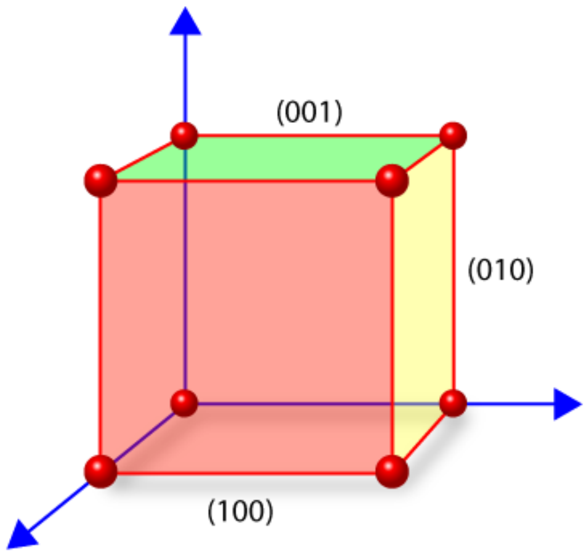
Referring to the graphic "*Cartesian Coordinates*", the

- x-axis vector direction is denoted [1,0,0]
- y-axis vector direction is denoted [0,1,0]
- z-axis vector direction is denoted [0,0,1]

(Think of the "1" as being "1 unit" out from the origin or 0,0,0.)



Cartesian Coordinates



Crystal planes, each perpendicular to its respective vector (or axis)

Crystal planes are perpendicular to their corresponding axis. For example, the plane perpendicular to the [1,0,0] vector or x-axis is the (1,0,0) plane (shown in the figure). Each crystal plane has a unique notation.

- (1,0,0) or (100) is perpendicular to the x-axis
- (0,1,0) or (010) is perpendicular to the y-axis
- (0,0,1) or (001) is perpendicular to the z-axis

Crystal orientations (100) and (111) are commonly used for microsystems fabrication.

Activity Objectives and Outcomes

Activity Objectives

- Using the Japanese art of origami, folding paper into objects, you will construct a rhombicuboctahedron that represents a silicon crystal.

Activity Outcomes

The final product must have clean edges and flat faces. When you work in a small startup company or even a large research lab, many tasks are performed by hand. Attention to detail as well as fine motor skills is a premium! Your outcome should show that you planned your strategy before tackling this task. Take your time and build a quality product! Try not to have excessive tape or glue showing on the finished work. Once constructed you will be asked to interpret the information on at least three of the origami faces.

Resources

Template by Jack Judy, Associate Professor, Electrical Engineering, UCLA

Supplies

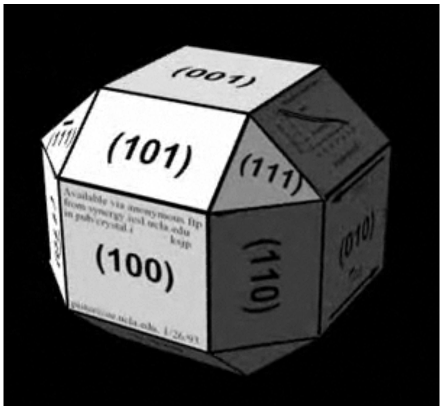
- 12 origami templates printed on cardstock are contained in the SCME Crystallography kit. If you do not have the kit, you can go to http://www-bsac.eecs.berkeley.edu/~pister/crystal.pdf for the template.
- A pair of thin scissors, Exacto knife, or razor blade

Documentation

- The silicon crystal cube
- Post Activity Questions with answers

Activity: An Origami Crystal

NOTE: For simplification purposes, we will refer to the final outcome as a "cube" rather than a rhombicuboctahedron or polyhedral. The image to the right shows the constructed origami crystal.



Procedure:

1. Watch the video "Origami Crystal animation". (https://youtu.be/-kWu4--n1JQ)
2. Carefully cut out the template provided. Be sure to cut along the thin lines.
3. Fold the tabs and carefully construct the cube. You may have to try several times in order to get it to fit together correctly.
4. Use a small amount of glue or double sided tape to hold your cube together.
5. If you make a mistake and need a new template, be sure to print the template on heavy paper or cardstock.
6. Answer the Post-Activity Questions.

Post-Activity Questions

1. How do the faces of this cube relate to a silicon crystal?
2. What do the "folds" represent relative to a silicon crystal?
3. What is the difference between (010) and $(0\bar{1}0)$?
4. Why is crystal orientation important in the fabrication of microdevices?
5. Look carefully at the final cube. What can you say about the importance of crystal orientation related to following:
   a. Etch rates on the exposed planes?
   b. Oxidation growth rates on the exposed planes?

Post-Activity Questions / Answers

1. How do the faces of this cube relate to a silicon crystal?

   Answer: Each face represents a crystal plane orientation: (100), (001), (011), (101), (010), (111)

2. What do the "folds" represent relative to a silicon crystal?

   Answer: Each fold represents the intersection of two planes.

3. What is the difference between (010) and $(0\bar{1}0)$?

   Answer: In Miller Index, the overstrike indicates a negative intercept of an axis; in this case, the y axis. It is the plane perpendicular to the $[0\bar{1}0]$ ***direction.***

4. Why is crystal orientation important in the fabrication of microdevices?

   Answer: Microsystems consist of structures with defined edges, lengths, widths or thicknesses. They also require certain
   - ***electrical (e.g. resistance),***
   - ***mechanical (e.g. bulk modulus), and***
   - ***optical (Index of Refraction) properties for translucent materials.***

   Each of these properties can be different for different orientations.

   Depending on the crystal orientation, you can anisotropically bulk etch structures such as v-grooves, mesas, pyramid points and cavities into the crystal silicon.

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