Nanopatterning with Lithography

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In this Activity, students learn the general principles of serial and parallel nanofabrication techniques. Using a macroscale analogy, students explore the parallel fabrication technique known as nanosphere lithography to create patterns.

Background

Nanoscience is the study of material properties on the nanometer scale (10^{-9} m), a size regime between atoms/molecules and bulk materials. All physical and chemical properties are size-dependent, and the properties of nanosize materials have important consequences in many scientific disciplines. Exploiting nanoscale behavior will lead to devices that can selectively attack diseased cells, increase computer processing speed, or sense pollutants.

Integrating the Activity into Your Curriculum

This Activity can be integrated into discussions on the transition from individual atoms to extended structures. Instructors can draw parallels to atom packing in solids. Be sure to emphasize the size difference between nanospheres (nanometers) and atoms (tenths of nanometers). The Activity could be used to emphasize geometry concepts.

About the Activity

Ask students to predict, based on considerations of geometry, how many spheres the triangular frame will hold. Depending on how the craft sticks are glued together, triangular frames hold 10–15 1-in.-diameter spheres. Students should place 5 of these spheres into a triangular frame and then agitate the frame while keeping the frame and contained spheres in contact with the working surface. Students should recognize that close-packing occurs most naturally. A source for nylon spheres is below *(1)*. Marbles or small balls may be substituted for the nylon spheres. It is crucial that students sprinkle only a very thin layer of talcum powder onto the contact paper. Instead of talcum powder, instructors could have students clap dusty chalkboard erasers over the sphere mask.

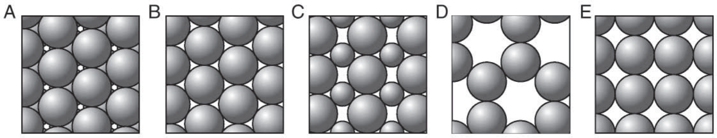
Students can achieve varied "nanostructure" patterns with different frames, multiple sphere layers, and different sphere sizes together.

Answers to Questions

1. When the spheres are close-packed, a three-fold hole is formed in every place where three spheres come together. When powder is shaken over the spheres, only the holes provide a route for the powder to reach the surface. The openings in the sphere arrangement determine the resulting pattern.
2. First, calculate the area formed by the triangular craft stick frame (area = 1/2 × base × height). Then, calculate the area occupied by the spheres (# of spheres × π(radius of one sphere)^2). When close-packed, spheres fill 92.8% of the triangle's area while 7.2% of the area is exposed to the surface below.
3. The method is a parallel process. Sprinkling the powder over the spheres simultaneously produces many identical features, rather than fabricating unique features one at a time (serial process).
4. Including different-sized spheres disrupts the close-packing arrangement. Although these disruptions cause disorder in the masks, they can also be exploited to yield novel patterns.

Additional Activity

To make the Activity analogous to photolithography, use a UV lamp and photosensitive paper instead of talcum powder and contact paper. UV light passes through the spheres to develop a pattern on the photosensitive paper.



Solutions for the nanopatterning challenge structures.

References, Additional Related Activities, and Demonstrations

1. McMaster-Carr Supply Company. *http://www.mcmaster.com;* 630/833–0300. Low-density polyethylene spheres: 1 in. diameter: #8487K27, 3/4 in. diameter: #8487K23 *(accessed Feb 2005)*.
2. Haynes, C. L.; Van Duyne, R. P. Nanosphere Lithography: A Versatile Nanofabrication Tool for Studies of Size-Dependent Nanoparticle Optics. *J. Phys. Chem. B* **2001**, *105,* 5599.

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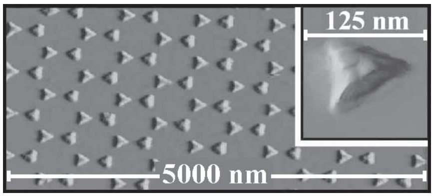
perforated

Nanopatterning with Lithography

To make nanoscale objects, scientists use two major techniques: top-down and bottom-up fabrication. (Grasping the size of nanoscale objects becomes easier with an analogy. The number of spheres 1 nanometer in diameter that would fit inside a softball is the same as the number of softballs needed to fill an object the size of Earth.) In top-down fabrication, scientists start with a (relatively) large object and cut it into smaller pieces until it is nanosized. In bottom-up fabrication, scientists build an object atom-by-atom until it is nanosized. If a dime (~ 1 mm thick) was sliced into nanometer-thick slices, with one slice made each second, it would take almost 12 days to convert one dime into nanoscale pieces. On the other hand, consider making a single spherical gold particle that is 13 nanometers in diameter by adding one atom at a time. If one gold atom is added every second, it would take more than one day to fabricate a single nanoparticle. Because most scientific experiments require thousands of nanoparticles, it would take years to fabricate enough particles for an experiment. To save time, scientists use techniques that create many nanoparticles simultaneously.

Some experiments require a few nanoparticles with a particular shape, size, and composition. Serial fabrication is used to create unique nanostructures. These structures are produced one at a time, much like writing with a nanosized pencil. Other experiments require many nanoparticles of approximately the same size, shape, and composition. Parallel fabrication is used to create many nearly identical structures at the same time, much like using an ice cube tray.



An atomic force micrograph of silver nanoparticles fabricated using nanosphere lithography.

Nanosphere lithography creates nanoparticles of the desired size, shape, and composition. A mask of nanospheres is used as a template. Material is deposited onto and through the mask onto an underlying layer, or substrate. The nanospheres are then removed with solvent, leaving only the material that reached the substrate by passing through the holes in the mask. The nanosphere arrangement determines the hole arrangement, and accordingly, the nanoscale pattern. In this Activity, you will explore a representation of nanosphere lithography. You will use 1-in. nylon spheres as a nanosphere mask and talcum powder as the material deposited through the mask to form desired particle patterns.

Try This

You will need: 4 craft sticks; glue; clear contact paper; ten 1-in. nylon spheres; ten 3/4-in. nylon spheres; two paper clips; talcum powder; scissors; tape; and dark-colored construction paper.

__1. Make an equilateral triangle-shaped frame using three craft sticks and glue. Allow the glue to dry.

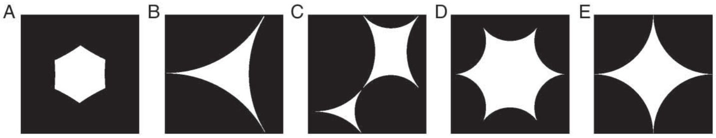
__2. Cut 5-in. × 5-in. pieces of clear contact paper and dark-colored construction paper. Remove the protective paper backing from the contact paper. Place the contact paper *adhesive side up* on a flat surface. Secure the corners of the clear contact paper to the surface with tape. Place the frame from step 1 on top of the contact paper.

__3. Assemble the sphere mask by placing as many 1-in. nylon spheres as possible into the frame. Make sure the spheres are closely packed. If extra space remains, reduce the size of your frame by attaching an extra craft stick to one side of the frame with paper clips.

__4. Dip your fingers in a small amount of talcum powder. Tap your fingers together above the sphere mask to sprinkle a very thin layer of talcum powder over and through the sphere mask, being careful not to inhale the talcum powder. Continue to sprinkle the powder until there is a clear pattern created on the adhesive contact paper.

__5. Remove the masking spheres and frame. Be careful not to let excess powder from the spheres fall onto the contact paper. Press the piece of dark-colored construction paper from step 2 on top of the contact paper and then turn the contact paper/construction paper "sandwich" over. This should preserve the pattern of powder.

__6. How many different-shaped particle patterns can be made using one or both sizes of spheres as a mask? Consider constructing different-shaped frames to evaluate the effect on close-packing. See the figure on this page for challenge structures.



Challenge structures: arrange the spheres to create a repeating pattern of each challenge "nanoparticle".

Questions

1. What is the qualitative relationship between the arrangement of the close-packed spheres and the resulting powder pattern?
2. Use geometric calculations of area to determine what percentage of the total area within the frame the spheres cover and what percentage of the area is exposed when the spheres are close-packed.
3. Is the nanosphere lithography fabrication method serial or parallel? Explain.
4. What happens when two different sphere sizes are used to create a single-level mask?

Information from the World Wide Web *(accessed Feb 2005)*

1. National Nanotechnology Initiative: For Students K–12. *http://www.nano.gov/html/edu/eduk12.html*
2. University of Wisconsin's Nanoworld Cineplex: Self-Assembly Movie. *http://www.mrsec.wisc.edu/Edetc/cineplex/self/index.html*