# MAKING STUFF WITH DAVID POGUE


# DEMONSTRATION
## Nanowires and the Ever-Shrinking Microchip

NOVA PBS

WGBH GRATEFULLY ACKNOWLEDGES THE CONTRIBUTION OF THE MATERIALS RESEARCH SOCIETY.

# MAKING STUFF SMALLER Demonstration

## Overview

**TITLE**
Nanowires and the Ever-Shrinking Microchip

**SHOW**
*Making Stuff: Smaller*

**DESCRIPTION**
Visitors will use a Styrofoam® block and pipe cleaners to demonstrate the challenge of working on the nanoscale (placing millions of wires and transistors onto tiny chips) to produce smaller but more powerful computing and electronic devices.

**OBJECTIVE**
Visitors will learn:

- how challenging it is to work on the small scale
- that materials scientists are developing extremely small, thin wires, called nanowires, that may help make computers and electronics even smaller in the future

**OTHER KEY TALKING POINTS**

- the nanoscale is too small to see
- scientists are discovering how to build small materials—objects measured in nanometers, or billionths of a meter—to create amazing new technologies. This is called nanotechnology.

**AUDIENCE**
General public, ages 10 and up

**TIME**
10-15 minutes

Yesterday's room-sized supercomputers are today's miniature microchips. Today's smaller devices are more portable, cost less to make, consume less power, and have longer-lasting batteries. But how small can we go? How much power and performance can we squeeze out of ever-shrinking microchips?

A nanometer is one-billionth of a meter, which is thousands of times smaller than the width of a human hair. The nanochip does not yet exist, but materials scientists and engineers are steadily advancing toward nanocomputing. Creating materials at that scale raises unique challenges—electrons that jump their wires, circuits that overheat, and the need for super-tiny tools and innovative manufacturing techniques to create nanoscale objects.

Materials scientists are asking:

- How can we make stuff even smaller and more powerful?
- How can new materials push beyond our current limits?

## Science Background

### NANOTECHNOLOGY AND THE NANOSCALE

The components of today's electronics are measured on the macroscale (visible to the naked eye) and microscopic (visible using a microscope) scale. But to push the limits of "smaller," materials scientists are investigating how to build and work on the **nanoscale** (one billionth of a meter). Nanoscale objects are billions of times smaller than everyday objects measured on the macroscale.

- **Macroscale**: Objects on this scale are measured in kilometers/miles, meters/yards, centimeters (one hundredth of a meter)/inches and millimeters (one thousandth of a meter)/fractions of an inch. Examples include:
  - Meter: height of a two-year-old child, medium-sized dog, poster, or some plants and shrubs
  - Millimeter: width of a pin head, thickness of a dime, thickness of some cardboard
- **Microscale**: Objects on this scale are measured in millionths of a meter. Examples include:
  - Micrometer: human hairs (about 200 micrometers), pollen, red blood cells, baker's yeast, some bacteria

- **Nanoscale**: Objects less than 100 nanometers (billionths of a meter). Examples include:
  - Nanometer: viruses, width of strands of DNA and RNA, thickness of a cell membrane

**Nanotechnology** involves engineering new materials out of individual atoms and molecules. When you build things on such a small scale, things act differently than on our scale. For example:

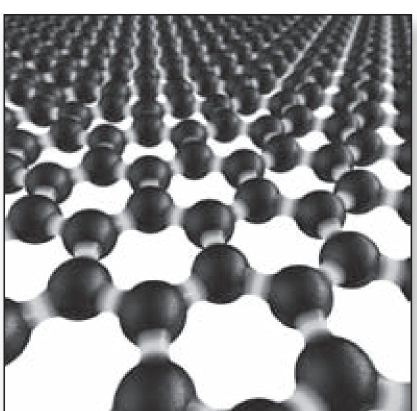
- Electrons jump from their extremely tiny wires to neighboring wires, rather than smoothly flowing the course laid out for them (called current leakage).
- Tightly packed, tiny components overheat more easily.
- Building tiny components requires very tiny tools.

One area of nanotechnology is the development of **nanowires**, which are wires thinner than 100 nanometers in diameter. Nanowires are so thin compared to their length that they are considered to be one-dimensional objects.

They can be made from metals, such as titanium or molybdenum, or non-metals, such as silica, which is the most common component of sand. One way nanowires are made is by dragging a thicker wire through a very hot flame using the tip of a tiny probe to thin it. They can also be made "from scratch" by combining atoms using several common laboratory techniques.

Materials scientists are designing some nanowires that conduct light instead of electrons, which will eliminate the problems with overheating circuits. Replacing silicon with a newly discovered form of carbon called graphene, which is a single-atom thick layer of carbon, may make possible new computer chips that allow electrons to move 1,000 times faster, making computers even more powerful.

The promise of nanotechnology goes beyond smaller, more powerful computers. Picture a TV screen that's a flexible film that you could roll up and put in your pocket. Or e-paper embedded with invisible nanowires that has the appearance of natural paper but is digital. Or new medical procedures to remove tumors without surgery or deliver medicine only where it is needed.



**Graphene** is a single-atom thick layer of carbon. The 2010 Nobel Prize in Physics was awarded for the discovery of this new form of carbon and its amazing physical properties.

# Materials List

- a collection of outdated electronics and computer equipment, plus any other items whose functions are now available on a smart phone. Select five or six from the below list*:

  atlas/map, calculator, calendar, camera (digital or film), CD, CD player, computer (desktop or laptop), cookbook, dictionary, DVD, DVD player, phone book, radio (desktop or portable), tape recorder, television, videocassettes, VCR player, video camera (digital or VHS), video games, video game unit
- 12 pipe cleaners, silver or gold tinsel, cut to 4" lengths
- 1 block** of green floral Styrofoam®, 4" wide x 4" long x 2" high
- 2 smaller green floral Styrofoam® blocks (e.g., 2" x 2", and 1" x 1")
- 1 dime
- Photos (see Resources)

  #1—circuit board

  #2—inside of microchip

  #3—microscopic image of wires on a microchip

  #4—microchip on a fingertip

  #5—a nanowire compared to a human hair
- Demonstration Title Sign and applications collage (see Resources)—mount on foam core or insert into a clear plastic display rack
- (optional) NOVA *Making Stuff: Smaller* video clip (see Resources) and video display equipment
- (optional) a real circuit board (e.g., from an old computer) in place of photo #1

For Resources, visit **pbs.org/nova/education/makingstuff**

*To obtain examples of outdated technology, ask neighbors and friends or inquire at IT departments, schools, and recycling centers, etc.

**The larger Styrofoam® block may be damaged during the demo, so have several on hand if the demonstration is to be repeated.

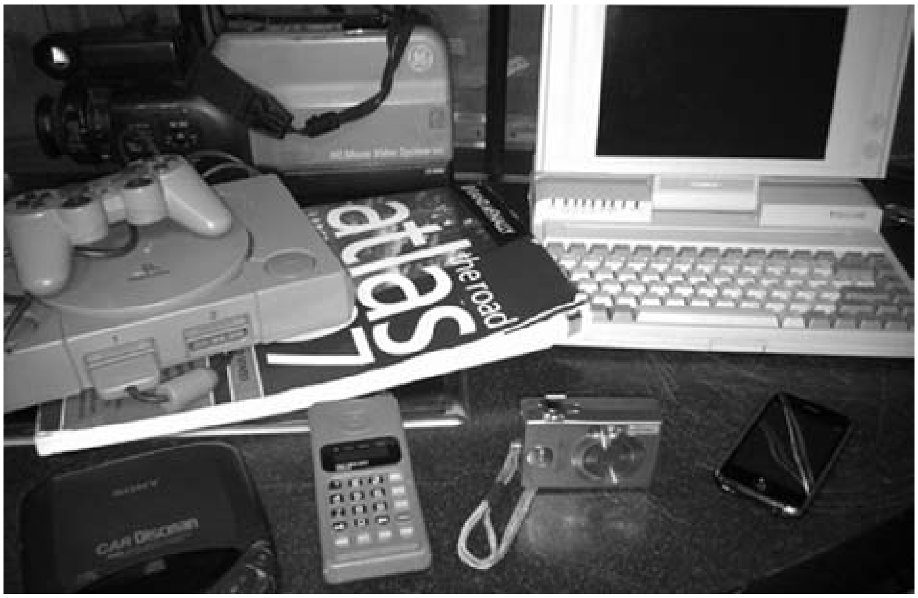
# Showing Video Clips from MAKING STUFF: SMALLER

If you are able to show video at the site of the demonstration, the video clip from NOVA's *Making Stuff: Smaller* can be used either as an introduction or as a follow-up to your demonstration. The clips can also be played on a continuous loop nearby to draw visitors into the demonstration area or before or after the demonstration.

# Advance Preparation

1. Test the demonstration in its entirety before performing it for an audience the first time.

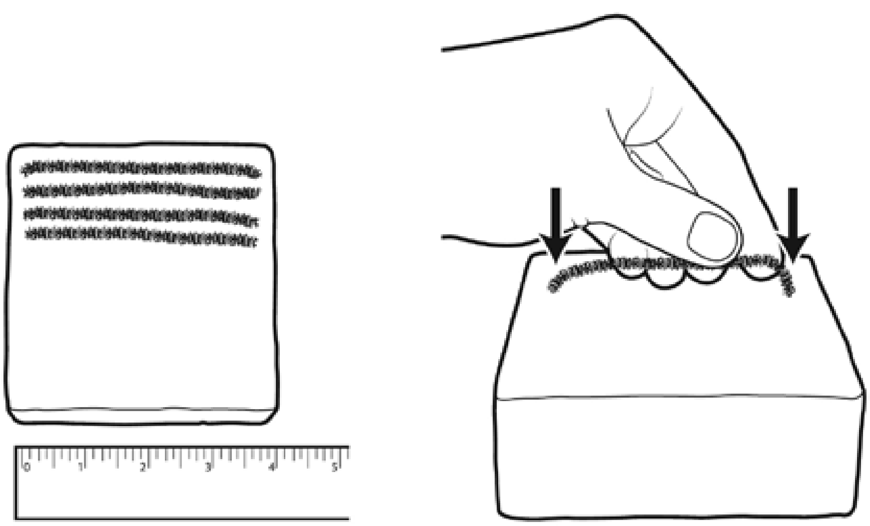
2. Set out in one group the collection of outdated technology, computing and electronic devices, and other items whose functions have been replaced by smart phones.



3. Insert several "starter" pipe cleaners in the 4" x 4" Styrofoam® block as an example as shown here.

4. Arrange the photos in the order they will be shown.

5. Post the Demonstration Title Sign on the cart/table.



**How to Insert the Pipe Cleaners on the Foam Block**

Insert five or six of the tinsel pipe cleaners into the block so visitors will have an example to follow. Bend the ends and punch them into the foam. Line them up and make sure they are not touching each other.

# Demonstration Script

1. **Welcome visitors** to the demonstration and briefly introduce the show. *"Welcome to this* Making Stuff *demonstration.* Making Stuff: Stronger, Smaller, Cleaner, Smarter *is a four-part NOVA series on materials science that will air on PBS in January 2011. This demonstration accompanies the* Making Stuff: Smaller *episode."*

2. **Engage your visitors.** Point out and name the outdated computers, electronics, and other items. *"So here we have a variety of items…."* **Ask**: *"Would all of this technology fit in your pocket?"* If someone says no, ask: *"Does anyone have a smart phone—a small device that has all of these functions and more?"*

3. **Think "small."** *"What are some advantages to having small electronics and computers, like the smart phone in your pocket?"* [Some answers: Smaller devices are more portable and less expensive to make; they consume less power, so batteries last longer.] *"You've probably noticed that electronics and computers keep getting smaller and smaller, while at the same time doing more, but how did that happen?"*

4. **Introduce the circuit board.** Hold up the real circuit board or photo #1 (circuit board) and say:
   - *"This is a circuit board, sometimes called a motherboard, which is found inside computers and other electronic devices.*
   - *It has many microchips—these small black squares and rectangles—that are the "brains" of the computer.*
   - *These are macroscale, or visible with the naked eye."*

**About the History of Computers**

- The "brains" of computers weren't always so small. One of the first computers, called Eniac, used vacuum tubes as switches. Eniac weighed 30 tons, took up 1,800 square feet, and cost half a million dollars (a lot of money in the 1940s), yet it had only the same computing capacity as a modern inexpensive calculator.
- Vacuum tubes were eventually replaced by transistors, the first of which were half an inch long (1.27 cm).
- Today, more than two billion transistors can fit on a chip that is one-centimeter square (0.15-inches square), or about half the size of a dime.

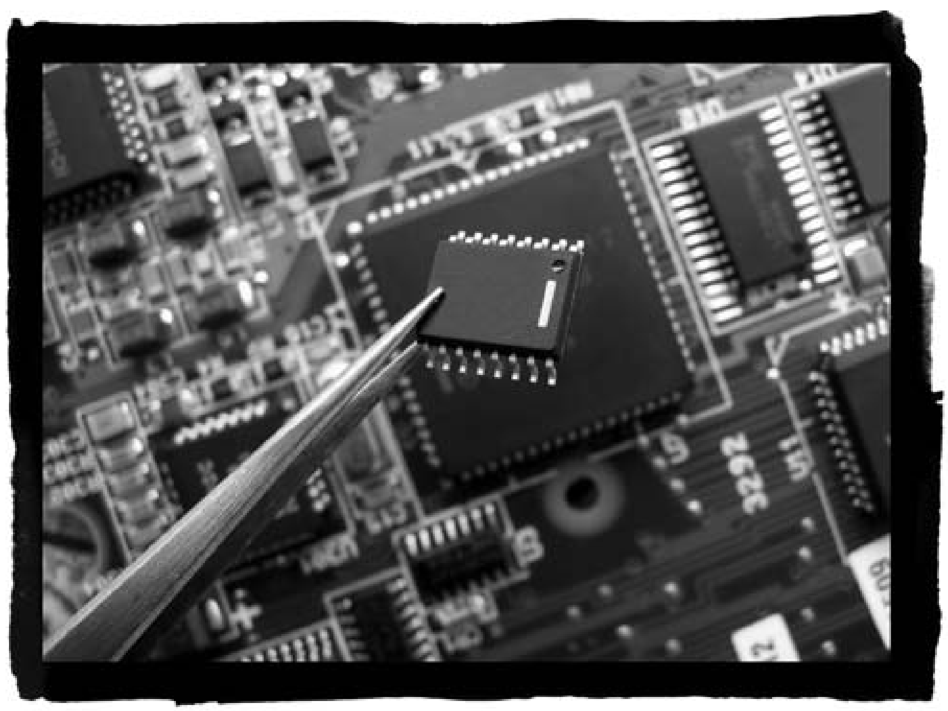


**Photo #1: Circuit Board**

Microchips and circuit board

5. **Introduce the microchip and transistor.** Hold up photo #2 of the inside of a microchip and say:
   - *"The inside of this microchip is an example of the **microscale**. This photo is magnified 40 times.*
   - *A **microchip** is a silicon wafer etched with extremely tiny metal wires and switches called transistors that make up miniaturized electrical circuits that process information.*
   - ***Transistors** are switches that turn a flow of electrons on and off. All electronics work by controlling the flow of electrons. In the last 60 years transistors became smaller, faster, and cheaper.*
   - *The more transistors you can fit on a chip, the greater the computing power and processing speed. Today, more than two billion transistors (that's 2,000 million) can fit on a chip that is about half the size of a dime (1 centimeter square/0.15 inches square)."* **Hold up the dime**.

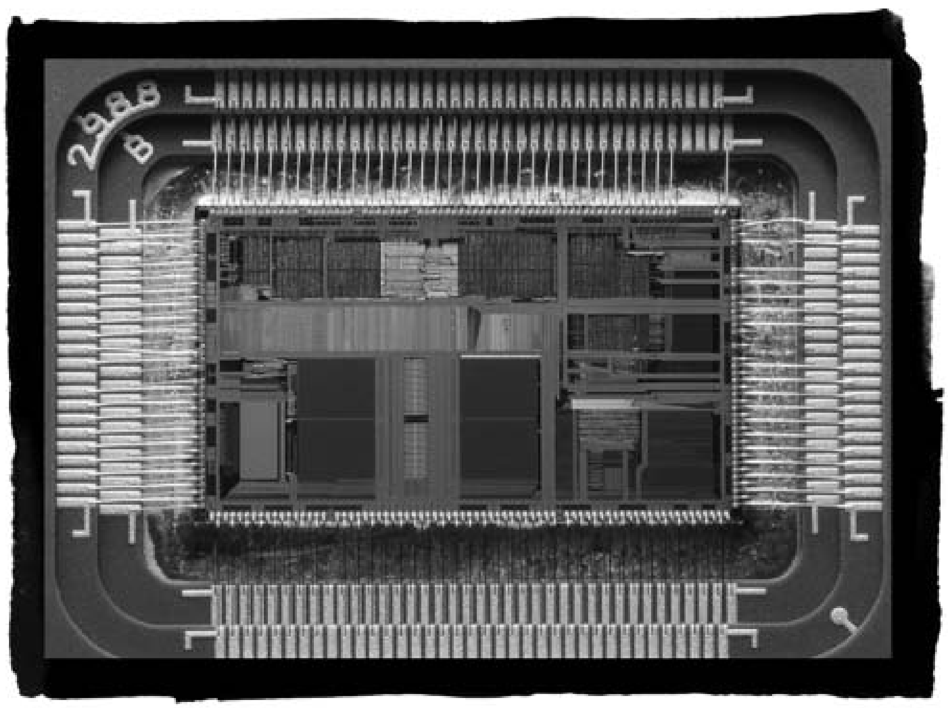



**Photo #2: A Microchip with the Cover Removed**

- This is a photo of the Intel 486 chip introduced in the early 1990s.
- It was the first chip to have **more than a million transistors.**
- The actual chip is only about **½-inch** by **¼-inch.**
- This photo is magnified **40 times.**
- However, even at that magnification it is difficult to see the tiny wires on the chip, which is the rectangle in the center.
- The outer edges are the packaging and the large wires connect the chip to the pins that attach to the motherboard.

6. **Discuss scale.** *"Although the components of today's electronics are very small, they are still visible with the naked eye (**macroscale**) or with a microscope (**microscale**).*
   - *But there is an even smaller scale called the **nanoscale**. Nano is 1,000 times smaller than the micro. It is named after a unit of measurement called the **nanometer**, which is one billionth of a meter. That's 25-millionths of an inch.*
   - *Nanoscale objects are too small to be seen with a microscope, although they can be imaged with special, very powerful tools."*

7. **Introduce nanotechnology.** *"Materials scientists and engineers now are discovering how to work on this scale to build small materials—mere clusters of atoms—to create amazing new technologies. This is called **nanotechnology**."*

8. **Describe the challenges of nanotechnology.** *"However, there are challenges to making things even smaller. For example*:
   - *It is difficult to work on such a small scale—new tools and materials are needed.*
   - *As more and more electronic components are placed in a small area, heat builds up due to the friction of the electrons flowing in the wires.*
   - **Hold up photo #3.** *"And, as the tiny wires get closer together, electrons can jump from one wire to another, making the circuit less efficient."*

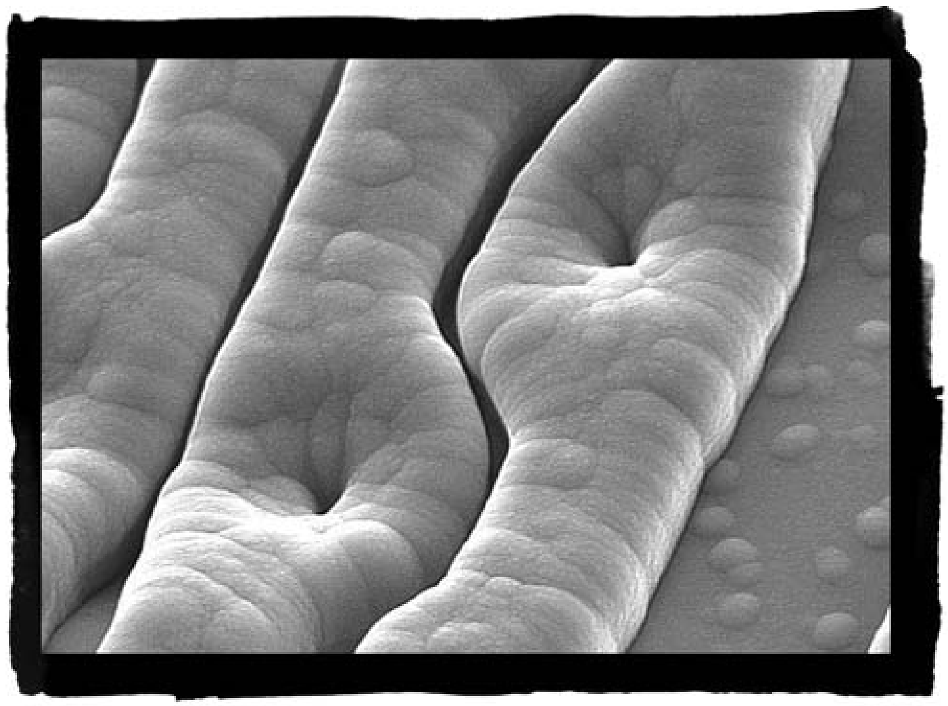


**Photo #3: A Scanning Electron Micrograph Image of Wires on a Microchip**

- This image shows the wires or connectors on a microchip magnified about **400 times.**
- When these wires get too close, the electrons can jump from one wire to the next.
- This makes the circuit much less efficient.

9. **Introduce the hands-on component.** Introduce the Styrofoam chip model as a way for visitors to see why working on the small scale is so challenging. The green block of Styrofoam represents a microchip and the pipe cleaners represent wires and transistors. Pass out one or two pipe cleaners to each visitor as you explain the goal of the exercise is to place as many wires onto the green block of Styrofoam as possible, following these rules:
   - Wires must lay flat with each end stuck firmly in the foam.
   - None of the wires can touch each other.

   [**Note**: Either keep the block at the cart and have the audience members approach one at a time to add their wires, or pass the block around the group, with members adding wires in turn.]

10. **Scale down and compare.** It will be difficult to get more than a dozen onto the block without touching. After the last wire has been added to the Styrofoam block, say: *"So you can see how challenging it is to work at this scale, the macroscale."* Hold up the successively smaller blocks of foam as you ask: *"Do you think it would be possible to fit the same number of components onto a chip this size? What about this size?"*

11. **Make the real-world connection.** Show photo #4 of the real microchip on the fingertip and ask: *"What if we were trying to fit even more components in an even smaller space?"* Solicit answers to the question: *"Does anyone have any ideas about how that could be done?"* Someone will likely say the obvious and key answer: Make the wires smaller.

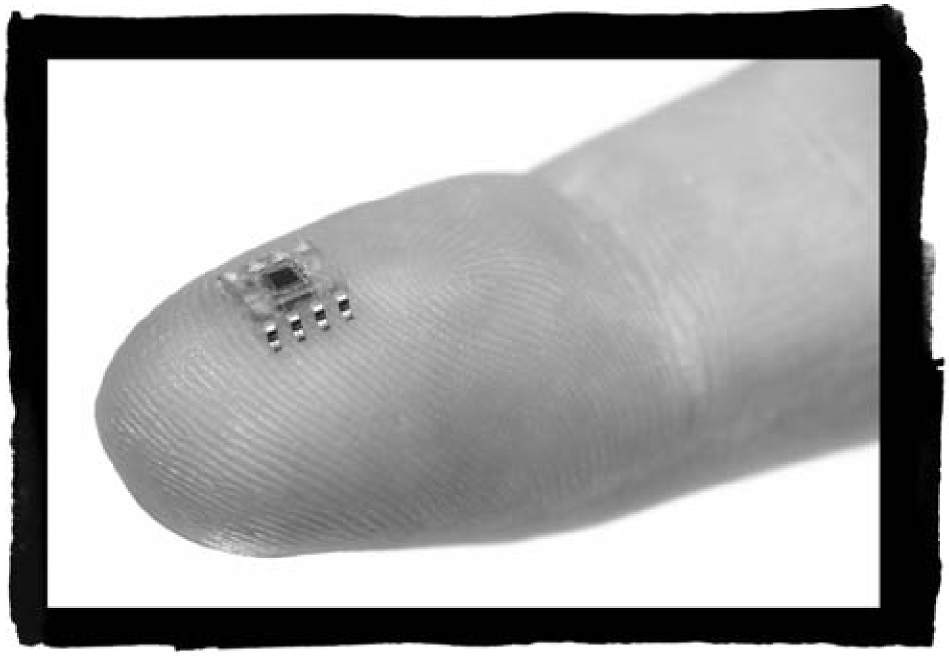


**Photo #4: A Microchip on a Fingertip for Scale**

12. **Introduce the concept of nanowires.** Say: *"Materials scientists and engineers are now developing* ***nanowires****, which are wires that have a thickness of about 100 nanometers or less."* Show photo #5 of the nanowire next to the human hair. Emphasize that it is a real photo, taken through a special microscope, and explain: *"The tiny, looped filament you see is just 50 nanometers wide. That's 1,000 times thinner than the single strand of human hair behind it."*

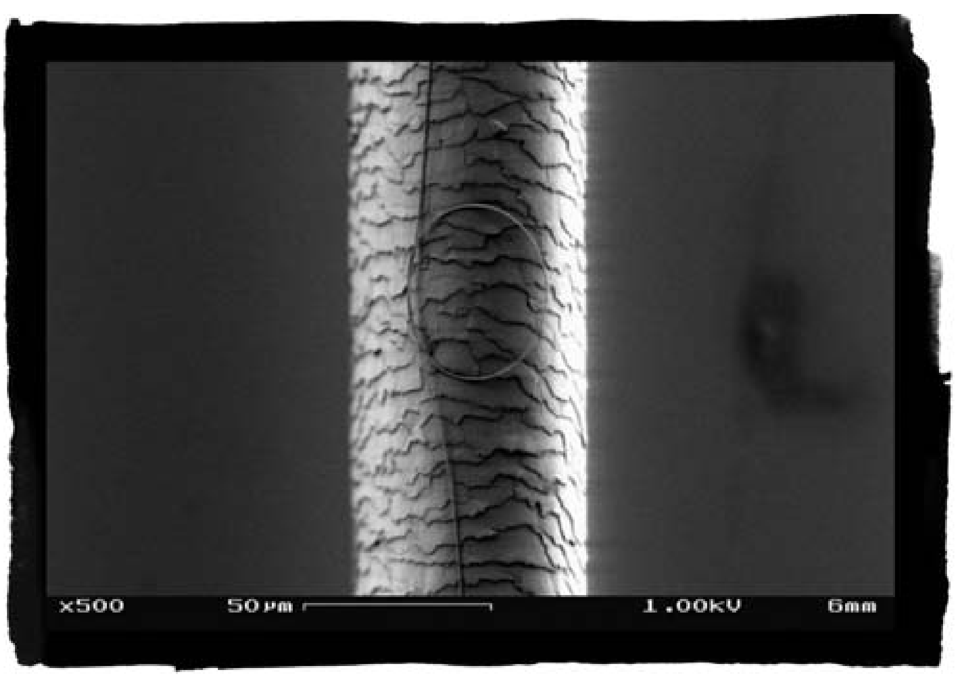



**Photo #5: A Nanowire Compared to a Human Hair**

- This is an image of a **nanowire** taken at **500 times** magnification.
- The **nanowire** is just 50 nanometers wide.
- The single strand of **hair** shown behind it is **1,000 times thicker.**

13. **Pass around the image** so everyone can get a closer view and explain: *"Nanowires could be used to make extremely tiny wires and transistors, resulting in smaller and more powerful computers and electronics as well as some of the other applications, including wearable computers and bendable TV screens."*

14. **Ask** if there are any questions and **share** some of the other applications below.

# Applications

**Potential Applications of Nanowires**

- A **television screen** so small, thin, and flexible that you could roll it up and carry it with you.
- A wearable **computer** with a bendable screen that could be mounted on your forearm.
- **E-paper** embedded with nanowires that could mimic real paper but is digital.
- Wires embedded in the windshield of your car (so small they are invisible) that, when activated, could create a **pop-up interactive display**.
- **Smart clothes** that generate electricity when you move.
- **Artificial skin** for prosthetics or robots.

# Frequently Asked Questions

**Q What does silicon have to do with computers?**

**A** The story of smaller, faster, cheaper computers began with the discovery of semiconductors. Silicon, the element that makes up most sand, has had a profound impact on our culture and the development of nanotechnology—despite being the sixth worst conductor in the periodic table of elements. In the 1940s and 1950s, scientists at Bell Labs discovered how to change the conductivity in semiconductors to make them work as switches. This made the miniaturization of transistors possible. Today, another element, carbon, is being manipulated at the atomic level to produce the next generation of small technology.

**Q What are some other uses of nanotechnology?**

**A** Some examples of products that currently use nanotechnology are sunscreens containing titanium particles that absorb harmful ultraviolet rays, socks containing silver particles that kill bacteria, and certain stain-resistant additives in fabrics. The applications of nanotechnology may change the future of not only computers and electronics but also medicine with the invention of exciting new applications such as pills that know what medicine to release into the body or tiny robots that repair damaged body parts.

# Glossary

- **macroscale**–objects on this scale are measured in kilometers or miles, meters or yards, centimeters (one hundredth of a meter) or inches, and millimeters (one thousandth of a meter) or fractions of an inch
- **microchip**–a silicon wafer etched with extremely tiny metal wires and switches called transistors that make up miniaturized electrical circuits that process information
- **microscale**–objects on this scale are measured in millionths of a meter
- **nanometer**–one-billionth of a meter
- **nanoscale**–objects on this scale are measured in billionths of a meter
- **nanotechnology**–technology involving objects usually less than 100 nanometers wide
- **nanowire**–a wire less than 100 nanometers wide; made of metals or non-metals
- **semiconductor**–a material that has more electrical conductivity than an insulator and less than a conductor, which makes it ideal for use in transistors
- **transistor**–a device made out of a semiconducting material that acts as a switch, controlling the flow of electrons, allowing information processing in electrical devices and computers

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