Q&A with a Photolithographic Process Engineer/Heavy Metal Rocker

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Cornell NanoScale Science & Technology Facility

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NANOOZE

This stencil, made with tape and an acrylic sheet, demonstrates how a photomask works in photolithography.

SCALE OF TINY THINGS

ITTY-BITTY TRANSISTORS AND CHIPS

NANOSCALE WEIRDNESS

PHOTOLITHOGRAPHY

HOW SMALL CAN WE GO?

ALL ABOUT THE THINGS TOO SMALL TO SEE

Welcome to Nanooze!

What is a Nanooze? (Sounds like *nah-news.*) Nanooze is not a thing, Nanooze is a place to hear about the latest exciting stuff in science and technology. What kind of stuff? Mostly discoveries about the part of our world that is too small to see and making tiny things using nanotechnology. Things like computer chips, the latest trends in fashion, and even important stuff like bicycles and tennis rackets. Nanooze was created for kids, so inside you'll find interesting articles about what nanotechnology is and what it might mean to your future. Nanooze is online at **nanooze.org**, or just Google "Nanooze"—you'll find interviews with real scientists, the latest in science news, games and more!

How can I get Nanooze in my classroom?

Copies of Nanooze are **FREE** for classroom teachers. Please visit **nanooze.org** for more information or email a request for copies to: info@nanooze.org.

What is small?

A nanometer is 1/1,000,000,000 (1 billionth) of a meter.

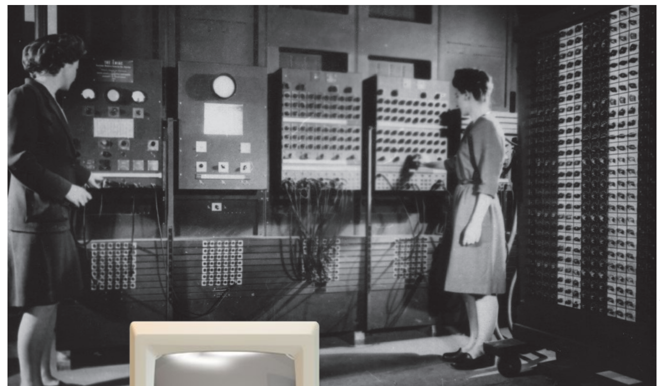
A nanometer is 1/1,000,000,000 (1 billionth) of a meter. Pluck a hair out of your head (one please) and look at it. A hair is 100,000 nanometers wide. Back about 20 years ago, the smallest transistor in a computer chip was about 100 nanometers. Today, there are transistors as small as five nanometers. That means that 20,000 modern transistors would fit across the width of a hair!

To put that into perspective, the Quicken Loans Arena, where the Cleveland Cavaliers play basketball, holds about 20,000 fans. Put them all in a single-file line with each fan putting their hands on the shoulders of the person in front of them and it is almost eight miles long. Transistors that are only five nanometers let you put a lot of them in a small space.

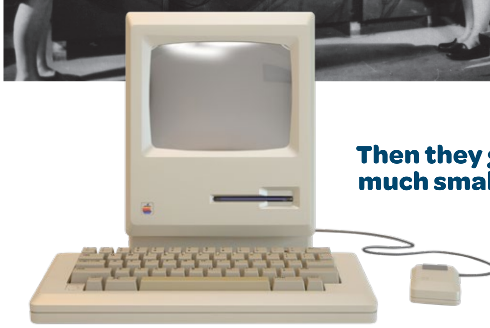
Making things that are too small to see is a challenge.

Instead of standard tools (hammers, saws, screwdrivers) and materials (wood, steel, marshmallows), nanometer-scale objects are made with different kinds of tools that use things like light and X-rays and materials like silicon, gold and copper.

Computers used to take up entire rooms!



U.S. Army Photo



Then they got much smaller...

Today, some computers can fit on your wrist!

NANO KNOW-HOW

Learning about nano stuff is fun, but it can be complex, so it helps to keep these four important facts in mind:

1. All things are made of atoms.

It's true! Most stuff, like you, your dog, your toothbrush, your computer, is made entirely of atoms. Things like light, sound and electricity are not made of atoms, but the sun, the earth and the moon are all made of atoms. That's a lot of atoms! And they're incredibly small. In fact, you could lay one million atoms across the head of a pin.

2. At the nanometer scale, atoms are in constant motion.

Even when water is frozen into ice, the water molecules are still moving. So how come we can't see them move? It's hard to imagine that each atom vibrates, but they are so tiny that it's impossible to see them move with our eyes.

3. Molecules have size and shape.

Atoms bond together to form molecules that have different sizes and shapes. For instance, water is a small molecule made up of two hydrogen atoms and one oxygen atom, so it is called H2O. All water molecules have the same shape because the bonds between the hydrogen atoms and the oxygen atom are more or less the same angle.

Single molecules can be made up of thousands and thousands of atoms. Insulin is a molecule in our bodies that helps to control the amount of sugar in our blood. It is made up of more than one thousand atoms! Scientists can map out the shapes of different molecules and can even build most types of molecules in the lab.

4. Molecules in their nanometer-scale environment have unexpected properties.

The rules at the nanometer scale are different than what we usually encounter in our human-sized environment. For instance, gravity doesn't count because other forces are more powerful at the molecular level. Static and surface tension become really important. What is cool about nanotechnology is that we can make things that don't behave like we expect. ***Things are really different down there!!***

Q&A

with Photolithographic Process Engineer Garry Bordonaro

What is your current job and what do you like about it? Photolithographic process engineer. I work with very sophisticated and complex optical printing tools and teach others to use them properly. Some of the work can be very challenging and difficult, but it is rewarding to see what can be accomplished.

What is a typical day like for you? I do lots of email, then go into the clean room to check on tools and materials. I will run training sessions for groups or individuals, depending on the number of new users that week. I spend a lot of time answering questions regarding processing and tool usage. I often have to troubleshoot tool or process problems and can spend a lot of time working on the solution. I spend too much time cleaning up after people!

When you were a kid, what did you want to be? And if it wasn't a scientist, what was it and why did you change your mind? I wanted to be a musician, and I was for several years. Eventually I needed a more stable environment and income to have a family, so I started working as a technician making scientific tools for a local company. I liked working on complex systems and decided to continue with scientific occupations.

What did you do to get your current job, and what kind of education did you need for it? I first worked in another department at Cornell doing technical work on high-voltage and high-vacuum systems. I was able to move to my current department after several years when they had an opening. I had experience with complex systems, computers and photography, all of which were involved in the work. I needed a better physics and chemistry education, but struggled through anyway. I had to learn a lot.

Tell us something fun about yourself? And it doesn't have to be about science! Over the past 15 years I have been able to return to my musician roots part-time. I have been able to play in many countries, including the US (of course), the UK, Germany, Sweden, Norway, Spain, Belgium, Brazil, Japan, and some other EU countries. I have traveled more during this time than I did when I was doing it for a living! It's also more fun now.

Garry leads training sessions in Cornell's nanofabrication lab.

Garry was a bass player for The Rods, a heavy metal band formed in the '80s. They reunited in 2008 and still tour today!

SMALL STUFF!

Nanometers are used to measure things that are really, really, *really* small. There are a billion nanometers in a meter, a hundred million nanometers in a centimeter and a million nanometers in a millimeter.

1,000,000nm
(1 millimeter)
Lincoln's nose on a penny

40,000nm
(0.04 millimeter)
Thickness of a human fingernail

NISE Network

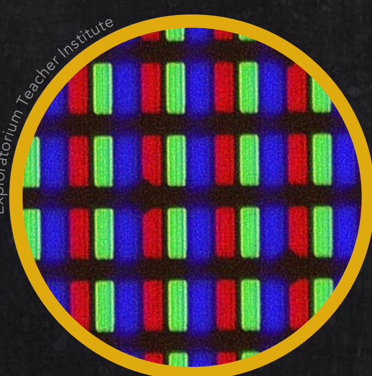
100,000nm
(0.1 millimeter)
Width of a human hair

Wellcome Collection / Annie Cavanagh

10,00
(0.01 m
Red blo

SPL / Science Source

2,000,000nm
(2 millimeters)
Head louse



Exploratorium Teacher Institute

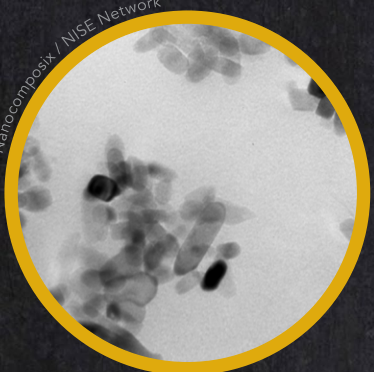
50,000nm
(0.05 millimeter)
Smartphone pixel

Some skincare products contain nanoparticles.

Did you know?
Your fingernails grow at the rate of about one nanometer per second! That works out to about a tenth of a millimeter a day.

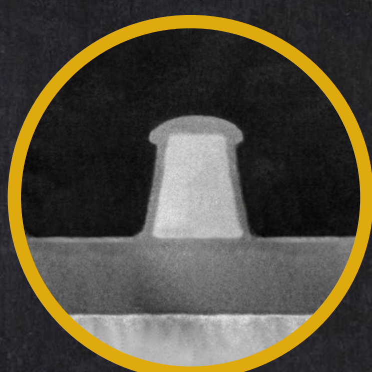
Smartphones would not be possible without tons of nanometer-sized parts.

Nanocomposix / NISE Network

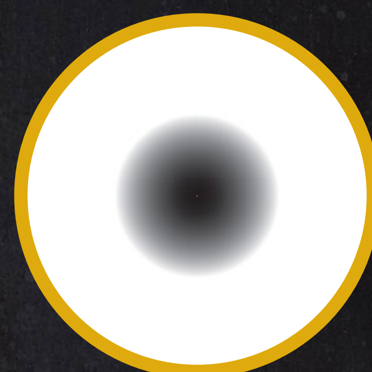


30nm
Nanoparticles in sunscreen

0nm
illimeter)
od cell

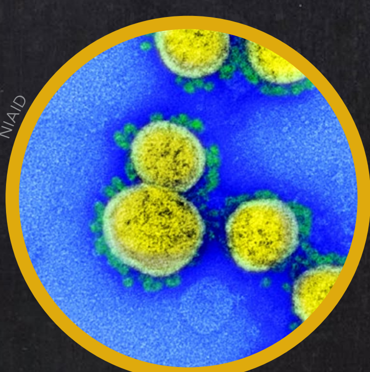


7nm
Transistor switch in a microchip



0.1nm
Single atom

NIAID



100nm
SARS-CoV-2 Coronavirus particle

Wikimedia Commons

2nm
Width of DNA

Those itty-bitty chips

GETTING DOWN TO 100 NANOMETERS

Back not too long ago, scientists and engineers were dreaming about things that were less than 100 nanometers in size. That is about 1/1000 the width of a hair. Crazy! As the tools and processes to make nanometer-scaled things got better, 100 nanometers was no longer impossible, and around the year 2000, the first transistors were made that were less than 100 nanometers in size. Fast-forward to the latest smartphones. How is a device that fits into your hand able to do so much? Smaller transistors!

SEVEN NANOMETERS AND COUNTING

The transistors in the newest smartphones are about seven nanometers in size. Just a few years ago, we at Nanooze were amazed by transistors that were 32 nanometers in size. Today? Boring. Going down to seven nanometers took a few years and some new ways of making nanometer-sized devices. These transistors were first introduced in the Apple A12 Bionic chip. It is made using a number of techniques including *extreme ultraviolet lithography*—wavelengths of light that are very short, only 193 nanometers in length. While it was once believed that the wavelength of light was going to make it impossible to make anything *smaller* than the wavelength of light, scientists discovered some tricks that allowed them to use 193-nanometer light to make things even smaller than 193 nanometers.

EXTREME ULTRAVIOLET LITHOGRAPHY

Think about the smallest thing you can see. With just your eyes you can see maybe a grain of sand. If you use a magnifying glass maybe you can see some bumps on that grain of sand. Extreme ultraviolet lithography goes far smaller. It is a new process that is being used to make parts of computer chips really, really small. This process has been made possible by using much shorter wavelengths of light as well as by building new lenses and changing how those lenses are arranged.

IMMERSION LENSES

One big technological advance is immersion lenses. Imagine you are in a boat looking down at the water. Depending upon the amount of sunshine reflecting off the surface, you might be able to see some things in the water. Now put on some swim goggles or a snorkel mask and stick your head in the water. You can see so much more! A special kind of lens called an *immersion lens* works in a similar way and is used in extreme ultraviolet lithography. An immersion lens is immersed in liquids that make their resolution much higher.

The Apple A12 Bionic chip was the first mass-market chip to be manufactured with extreme ultraviolet lithography.

Wikimeadia Commons

Tiny chips with nanometer-sized parts make everything on your smartphone possible!

S

How do we make ’em

TEENY-TINY SWITCHES

Inside your computer is a chip, and inside that chip are lots of really, *really* tiny switches called transistors. These switches are so small that you could put 1,000 of them across the width of a hair. Inside your average chip there are about 100,000,000 tiny switches. That is a lot of switches, but in a few years, even that won’t be enough!

MAKING TINY TRANSISTORS

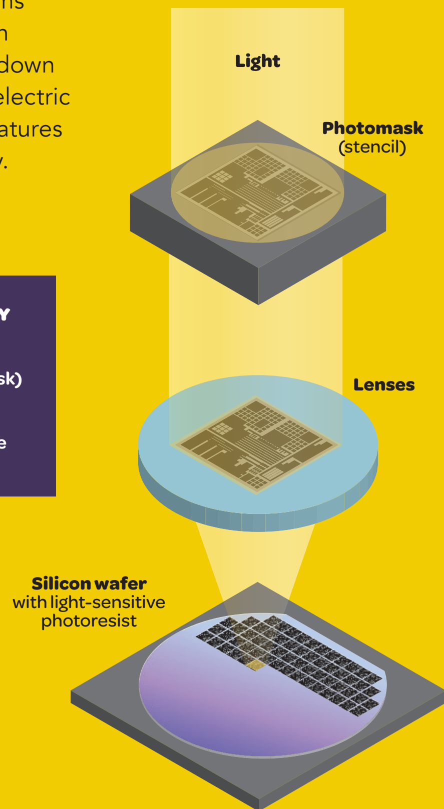
Scientists make these tiny switches using a process called *photolithography* that uses light and lenses to shrink patterns down to a few nanometers. Think of a microscope working backwards—instead of making small things bigger, this process makes big things small. Photolithography also uses light-sensitive chemicals whose properties change when they are exposed to a specific wavelength of light. So they become a solid that can’t be washed away after being exposed to light.

PATTERNS AND LENSES

To make patterns for chips, engineers use masks that are kind of like a stencil. These *photomasks* only let light through in certain places. Each part of a chip has a pattern that is shrunk down using a series of lenses. Light passes through the mask, then through the lenses, and what shines onto the light-sensitive silicon wafer is an exact replica of what is on the mask, just a lot smaller. Kind of like the sun paper you can buy that changes color when it is exposed to sunlight. By repeating these steps over and over again, engineers can build a lot of transistors that are intricately arranged on a tiny chip.

WAVES OF LIGHT AND ELECTRON BEAMS

It was once believed that the smallest object you could make using photolithography was limited by the wavelength of light. But some clever scientists figured out a way to predict how light would behave at dimensions much smaller than their wavelength, and now we are making stuff almost 10 times smaller. But using photolithography will only get you so far, and to make even smaller things, engineers use machines that shine electron beams instead of light. Electron beams can be focused down to less than 1nm using electric fields, and very small features can be made in this way.



PHOTOLITHOGRAPHY uses light to shrink a pattern from a stencil (also called a photomask) onto a material that is sensitive to light. This process is used to make computer chips.

Building with atoms—can it be done?

In the future, we will need to make switches out of just a few atoms. Sound impossible? Well, it is already being done. Scientists have made switches out of a few atoms, and these switches are only about one nanometer in size. That means we could fit 100,000 of them across the width of a hair. And we can put a hundred times more of them into our computer chip.

STENCILS AND SUN PAPER These stencils, made with tape and acrylic sheets, demonstrate how a photomask works in photolithography. The stencils were placed on sun paper and then exposed to sunlight.

The crazy reality of the

NANOSCALE

AS THINGS GET SMALLER AND SMALLER, SOMETIMES THEY GET DOWNRIGHT WEIRD.

WAVY WATER

Take a stick and put it into a stream of water. Look closely and it appears that the water is bending around the stick. Magic? Magnetic? No, it has to do with the interactions between the water molecules and the wood (cellulose) molecules. The attraction between the stick and the water molecules is enough to change their behavior. A few inches away from the stick and it looks like the stick doesn't exist.

FLOATING DUST

Go into a room that nobody has been in for a while and also hasn't been cleaned. If there is sunlight coming in through the window you can see dust particles that appear to stream from the window to the floor. You can almost see individual dust particles because the light diffracts off them. Things change behavior when they get small, and most of the time they behave in unexpected ways.

SILVER KILLERS AND RED GOLD

Big chunks of silver are shiny and make nice jewelry. Take that same silver and make it into nanoparticles and they become killers of bacteria. Turn that silver into a bullet and, well, supposedly it can be used to vanquish vampires and werewolves (just in case). Gold looks, well, gold-like in color when it is in a ring or a coin. But gold nanoparticles can create all sorts of colors, like red or orange, depending on their size and shape.

THE QUANTUM REALM

In the movie *Ant-Man and the Wasp,* Ant-Man goes into the quantum realm—a world that is smaller than molecules, even smaller than atoms. Because the quantum realm is the space between atoms, things are very strange there. Ant-Man has the special ability to shrink down to nanometer scale, which he uses to enter the quantum realm in search of his friend's wife. Now, we can't *really* shrink to the nanometer scale, but what is so cool about the quantum realm is that the rules we observe in nature don't really apply. So the laws of time and space don't exist, at least not the way we think of it.

In the quantum realm, you can't move around because gravity has no effect. There is also no light, so seeing things is impossible. Time doesn't exist—chances are you won't lose any sleep or miss your favorite TV show. Ant-Man could enter the quantum realm and return in the same moment. In this realm, every particle can be everywhere at once. Some very famous people, including Albert Einstein, have debated about what the rules of the quantum realm might be.

CATS IN BOXES

Back in 1935, Erwin Schrödinger proposed that in the quantum realm you can't be sure of anything until you measure it directly. Schrödinger's famous example states that if you have a cat in a box with a poisonous gas that had a 50/50 chance of being released at any time, the cat could be either dead or alive. Peek in the box and you then determine if the cat is alive or dead. If you do this a billion times, half of the time you open the box the cat will be alive, and the other half of the time the cat will, sadly, be dead. Before you open the box, the cat exists between the two different states, dead and alive. The same thing exists in the quantum realm: you don't know what's going on until you look. Of course, this was just a thought experiment and no cats were harmed!

STAINED GLASS
When gold particles get small enough, they can create red colors. Some stained-glass windows get their brilliant hues from gold nanoparticles.

SPL / Science Source

DUST PARTICLES
When dust particles get small enough, they can float in the air.