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MICROCHIP ADVENTURES:

A Journey into the World of Semiconductors

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Welcome! Join us on this grand mission to learn more about the world of semiconductors. To engage with this e-book, look for the:

WATCH, THINK, REFLECT, and **MAKE** icon prompts and make sure to find each mission to explore. They will challenge you to dig deeper into understanding semiconductors, semiconductor technology, the supply chain, and its impact on our world.

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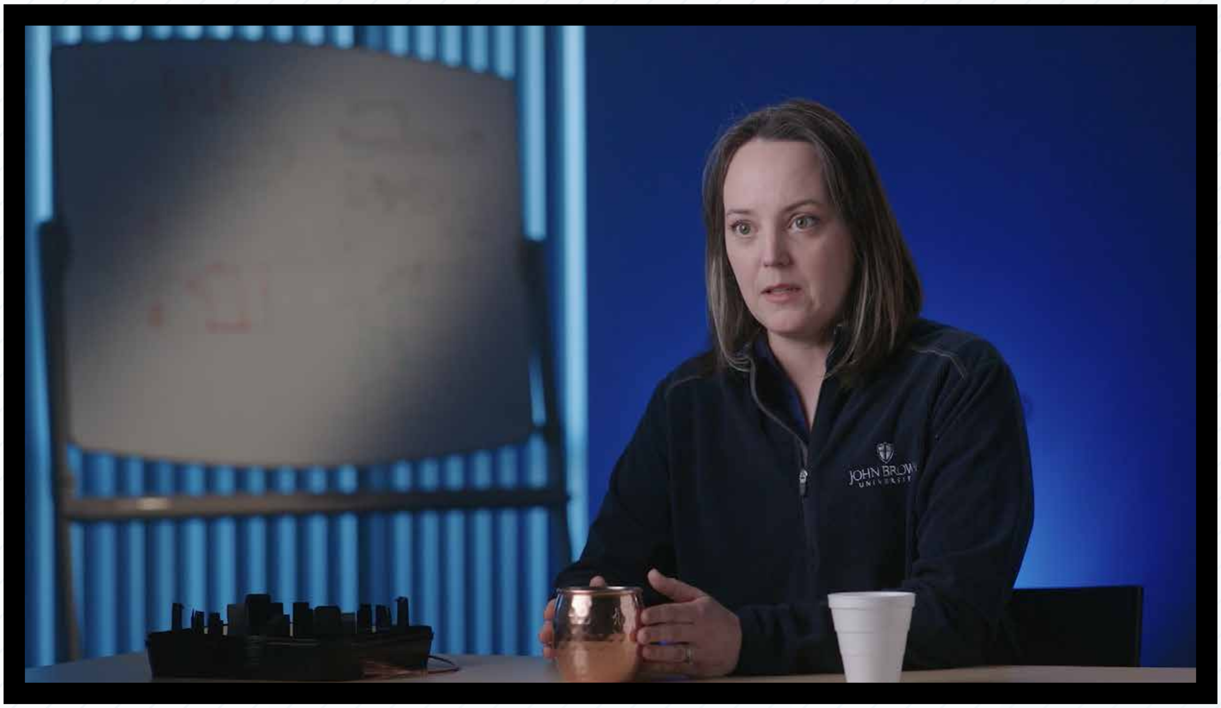
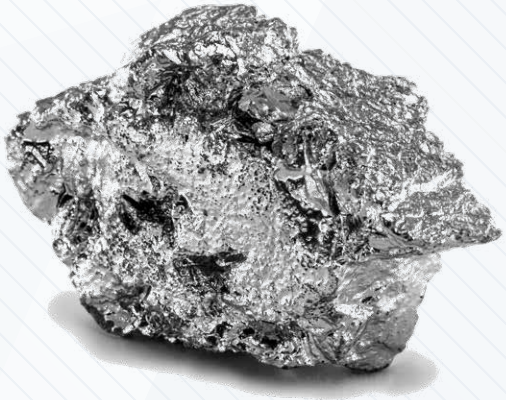


WATCH the video to learn what a semiconductor is, how it is made, and why it is so important!



What is a **Semiconductor?**

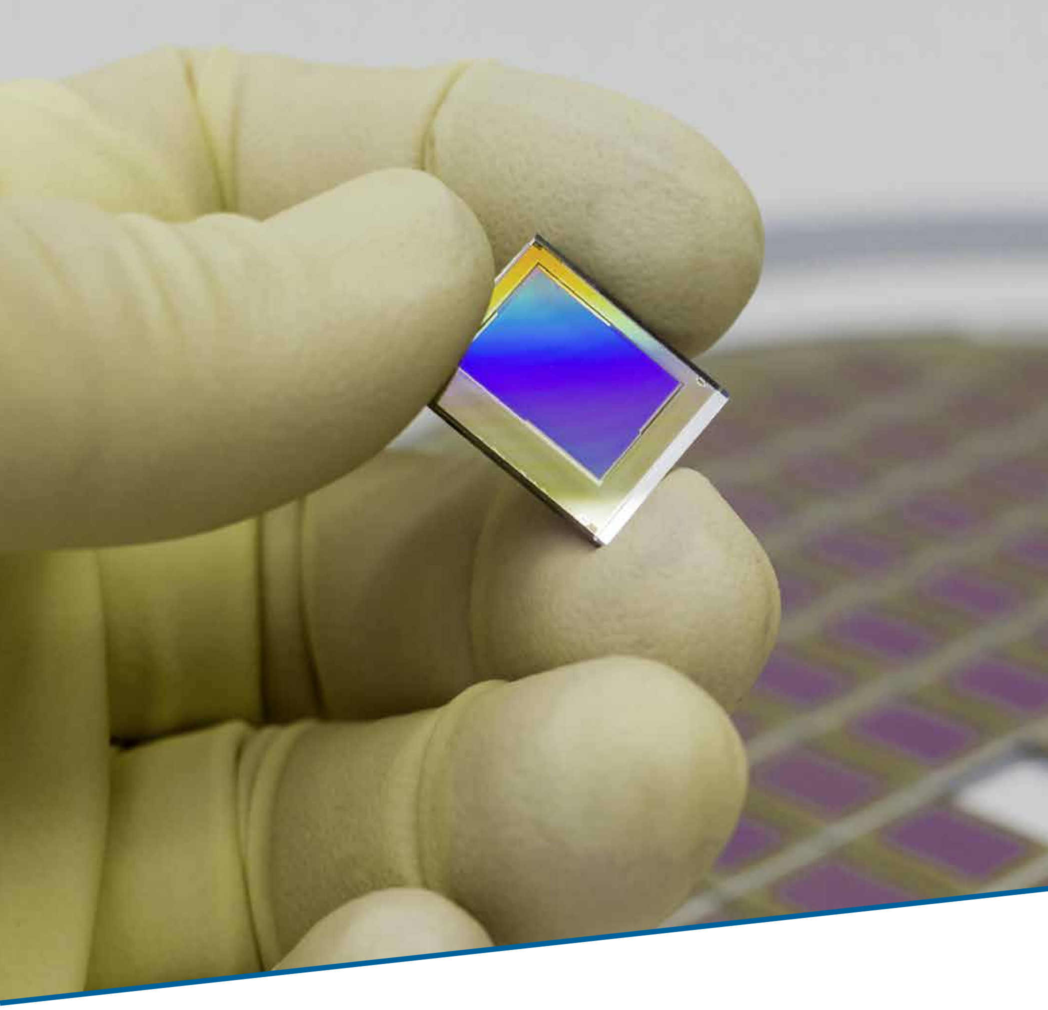
Let's review from the video, what exactly a semiconductor is. Well, first, what is a conductor? A conductor is a material that effectively conducts electricity, such as metal. There are also insulators - materials that can't conduct electricity, like rubber. A semiconductor is a unique material that can be made to do both! Sometimes it conducts, sometimes it doesn't. It can be used in things like computers and phones to make tiny switches called transistors.

Silicon is the most common semiconductor. It's like the **superhero** of electronics! By adding different atoms to silicon, we can change its behavior. We create two types of semiconductors: n-type (which has extra electrons) and p-type (which has "holes" where electrons can move around). We also use other semiconductor materials like germanium and compounds like gallium arsenide. They are just right for creating **electronic magic!**

Why are **Semiconductors Important?**

Semiconductors are the building blocks of modern electronics! Think of transistors (tiny switches) that control everything in your computer, phone, and other gadgets. Without semiconductors, we wouldn't have these amazing devices. So, remember: Semiconductors are like the "Goldilocks" of materials—they're not too conductive, not too insulating, but just right for powering our tech!

Semiconductors are in almost everything now: computers, smartphones, cars, household appliances, gaming systems, and medical equipment. As a result, semiconductors are incredibly important for today's economy, as they drive innovation and productivity in many industries.



MATERIALS MISSION:
Superhero of Electronics

Take on the role of semiconductor researcher. Dive deep into the science behind semiconductors, by using Phet Simulations, to explore conductors and insulators as well as discover how electrons move to create different types of semiconductors.

Semiconductor **Industry Lingo**

Semiconductors have a lot of nicknames! They are often referred to as integrated circuits (ICs), microchips, semis, chips, semiconductor chips, and also **wafers!** Let's clarify…

You already learned that a semiconductor is a special material that is both a conductor and an insulator of electricity. Semiconductor material (typically silicon) is used to make **wafers** that produce many **microchips.** One wafer can typically make 300-400 microchips.

The terms **microchip, semiconductor chip, semi, and chip** all refer to a microchip, which is an **integrated circuit (IC)** that is etched on the wafers. This integrated circuit (or microchip) is a small computer containing tiny switches (transistors) that perform arithmetic and logic operations and provide temporary memory storage. These chips are made using manufacturing techniques, **allowing billions of transistors to be packed into an area less than a 0.2 inch (5 millimeters) square.** Imagine it as a tiny, powerful brain that makes our gadgets work!

Source: Kids Britannica

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Chip Art

When engineers design integrated circuits, they use different shapes to make a plan. This plan is sometimes referred to as 'artwork,' but it's not the kind you hang on the wall. It's a blueprint for something amazing. These shapes are like a secret code that tells the machines what to build. As we will learn, these shapes get converted into metals, insulators, and semiconductors during manufacturing. But there are other kinds of art you can find on chips! Chip art, also known as silicon art, semiconductor art, silicon wafer art, or chip graffiti, refers to microscopic hidden doodles (designs, images, or messages) incorporated onto microchips during the manufacturing process. Engineers leave their creative mark on their tiny electronic canvases! One famous example was a hidden image of Waldo from the popular children's book series, "Where's Waldo?" that was found on the surface of a Texas Instruments silicon wafer in the late 1980s.

WATCH: To learn more about chip art watch this short video:
[Silicondoodle Medley by CPU Duke](#)

Source: https://www.devx.com/terms/chip-art/

Image Source: https://micro.magnet.fsu.edu/creatures/pages/waldo.html

FABRICATION MISSION:
Clean Lab

Take on the role of semiconductor engineers working in a foundry, or "Fab" (short for Fabrication Facilities), where you make microchips in a clean lab. Explore how a chip is made by making your own model with Play-Doh!

How are Chips Made?

What is a clean lab? In a clean lab, everything is ultra-clean. Why? Because even a speck of dust can mess up the chips! That speck of dust can interfere with the conductive network on a chip. Semiconductor engineers wear special suits (also called bunny suits since they are often all white, like a bunny rabbit!) and work in a room with air that is filtered to remove even the tiniest dust particles. It's a high-tech space where cleanliness is king!

While we don't have a clean room here, we can learn what happens in 'fab' by using a few fun materials like Play-Doh—with some real semiconductors mixed in—to stand in for our silicon, masks, and tools in the real fab.

MATERIALS NEEDED

- Play-Doh
- Sandwich Bag
- Index Card
- Pencil
- Scissor
- Cup
- Tweezers
- Batteries and Battery holder (4AA batteries)
- LEDs (5mm) - with legs trimmed shorter

STEP 1
Wafer

Silicon is mined and then made into an ingot. The ingot is sliced into thin "wafers."

MAKE: Begin with one layer of Play-Doh as the wafer.

STEP 2
Clean & Polish

The wafer is cleaned and polished.

MAKE: Cut a sandwich bag to match the size of your wafer. Cover your wafer with it to demonstrate the cleaning and polishing process.

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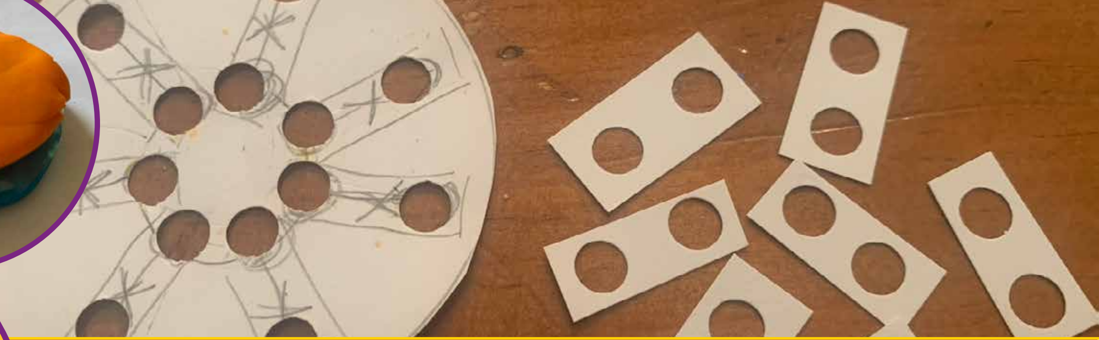


STEP 3

Photoresist Coating

After preparing the wafer, its surface is coated with a photoresist, a light-sensitive material.

MAKE: Add another layer of Play-Doh to model the photo resistant coating.

STEP 4

Photo Mask

The circuit design is turned into a mask (or stencil). To make the mask, the circuit design is drawn (or stamped) on the mask material and then cut out, leaving the mask or stencil of the "negative of the circuit." Light then transfers the imprinted circuit onto the wafer, revealing the parts intended for removal in the next step. We call this step of making the mask 'tapeout' since the masks used to be made with tape.

MAKE: Take the index card (cut out a 4" diameter circle as your wafer) and map out where to place 6-8 "chips" on your wafer. For this mission, chips will contain a single LED. There is a twist. In honor of the "Chip Art" we just learned about, we will turn our **chip layout into art.** Two constraints: (1) must have a minimum of 6 "chips" (2) must have a recognizable image (see image is the "sun"). Consider these other samples (mountain and city skyline).

DESIGN MISSION:

Art Infusion

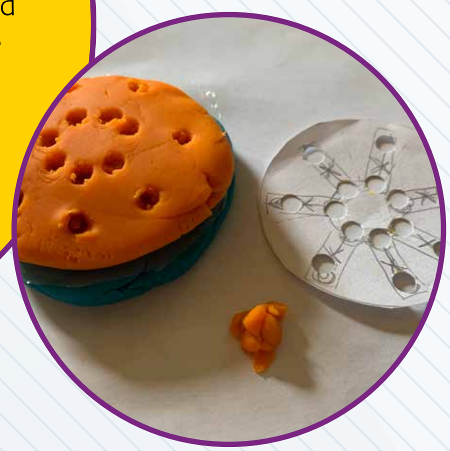
Take on the role of an **Integrated Circuit (IC) Designer.** In order to prepare you for the design mission you need to complete the Integrated Circuit Designer Certification by creating a circuit with Play-Doh, fondly known as Squishy Circuits. Once you are certified, you will create the "Mask," which is a stencil of the circuit design.

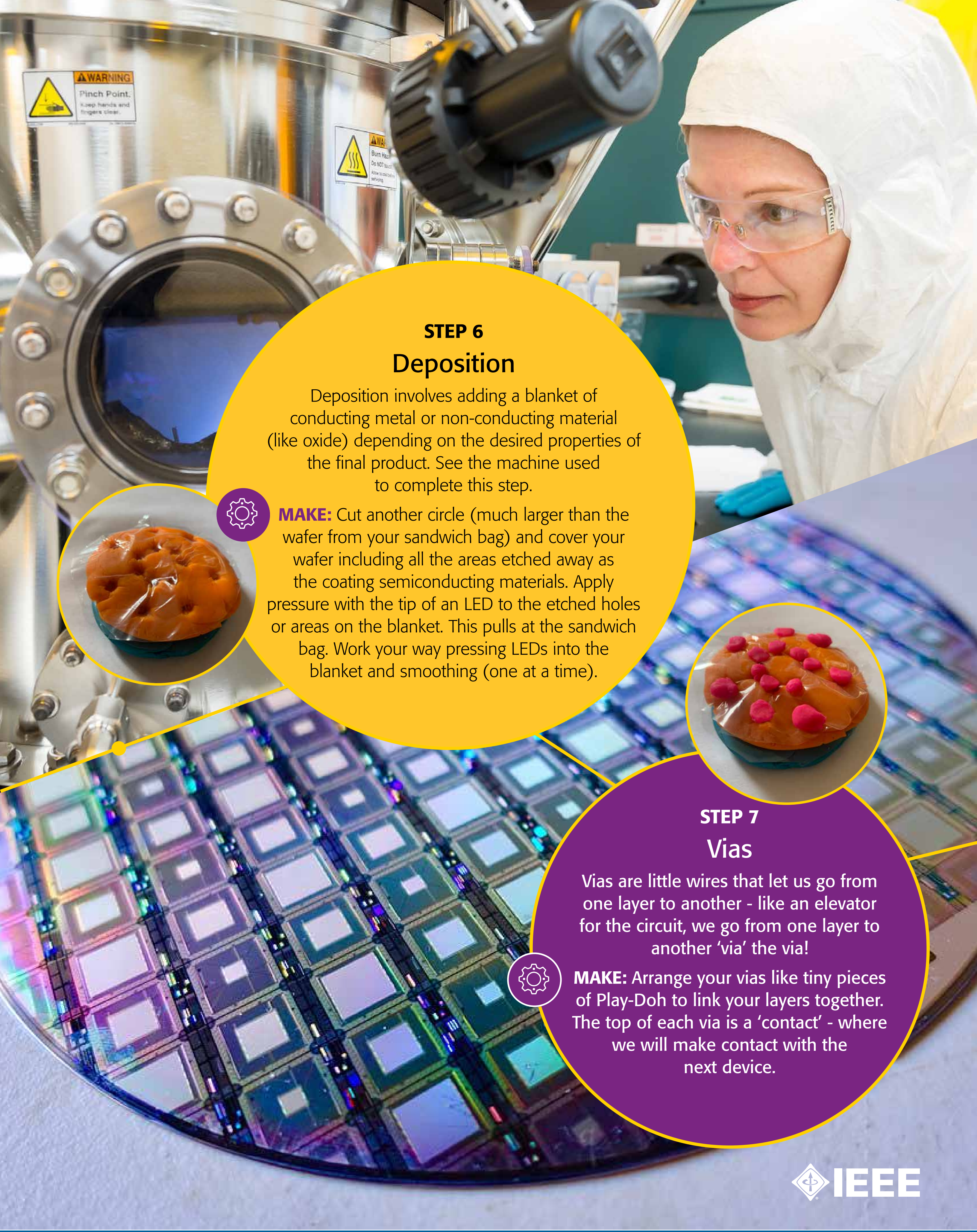
STEP 5

Etching

Etching is the process of removing unwanted material to create the chip's features using chemicals that eat away at the wafer's exposed areas, leaving behind the desired pattern. It also removes the underlying layers of silicon and other materials from the pattern of the circuit design.

MAKE: Use tweezers to remove the material exposed from your mask.





STEP 6

Deposition

Deposition involves adding a blanket of conducting metal or non-conducting material (like oxide) depending on the desired properties of the final product. See the machine used to complete this step.

MAKE: Cut another circle (much larger than the wafer from your sandwich bag) and cover your wafer including all the areas etched away as the coating semiconducting materials. Apply pressure with the tip of an LED to the etched holes or areas on the blanket. This pulls at the sandwich bag. Work your way pressing LEDs into the blanket and smoothing (one at a time).

STEP 7

Vias

Vias are little wires that let us go from one layer to another - like an elevator for the circuit, we go from one layer to another ‘via’ the via!

MAKE: Arrange your vias like tiny pieces of Play-Doh to link your layers together. The top of each via is a ‘contact’ - where we will make contact with the next device.

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STEP 8
Doping

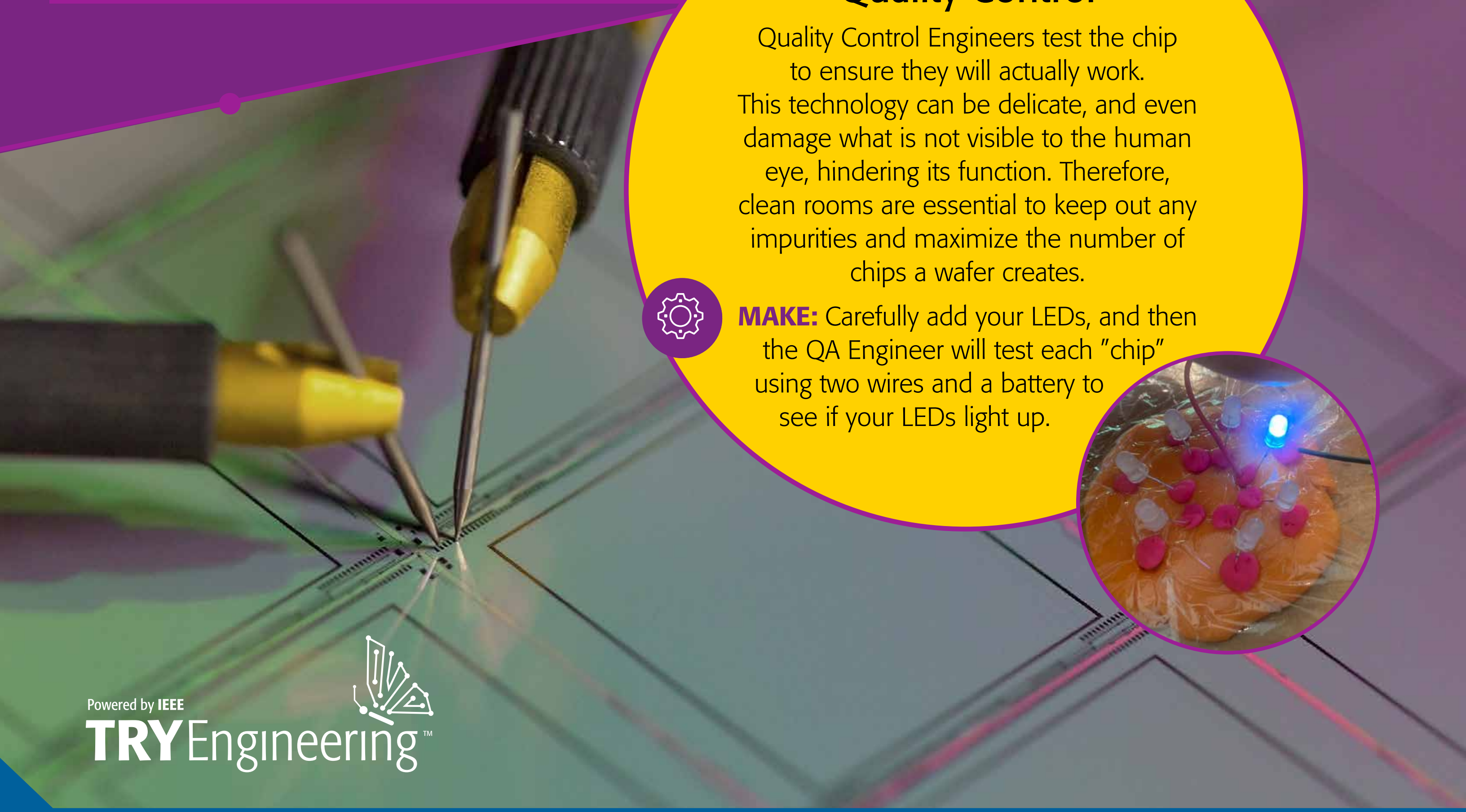
Doping, using an ion implanting machine, is the process of changing the properties of silicon in a wafer to create different chip components. We achieve this by introducing impurities into the silicon, altering its conductivity. The type and amount of impurities determine whether the silicon becomes n-type, which has an excess of electrons, or p-type, which has a shortage of electrons. Big machines called ion implanters manufacture these, and where n and p meet (a PN junction), they form the foundation of a transistor!

MAKE: Light-emitted diodes (LEDS) are actually just PN junctions, so since we don't have a big implanter, we place our already-made PN junctions (LEDS) from contact to contact to complete the circuit.

STEP 9
Layers

Multiple repetitions of the photolithography, etching, and doping processes build up the chip's complex structures. Each repetition adds a new layer to the chip, with each layer serving a specific function in the final circuit.

MAKE: Imagine you have repeated these steps to make multiple layers.



STEP 10
Quality Control

Quality Control Engineers test the chip to ensure they will actually work. This technology can be delicate, and even damage what is not visible to the human eye, hindering its function. Therefore, clean rooms are essential to keep out any impurities and maximize the number of chips a wafer creates.

MAKE: Carefully add your LEDs, and then the QA Engineer will test each "chip" using two wires and a battery to see if your LEDs light up.

STEP 11

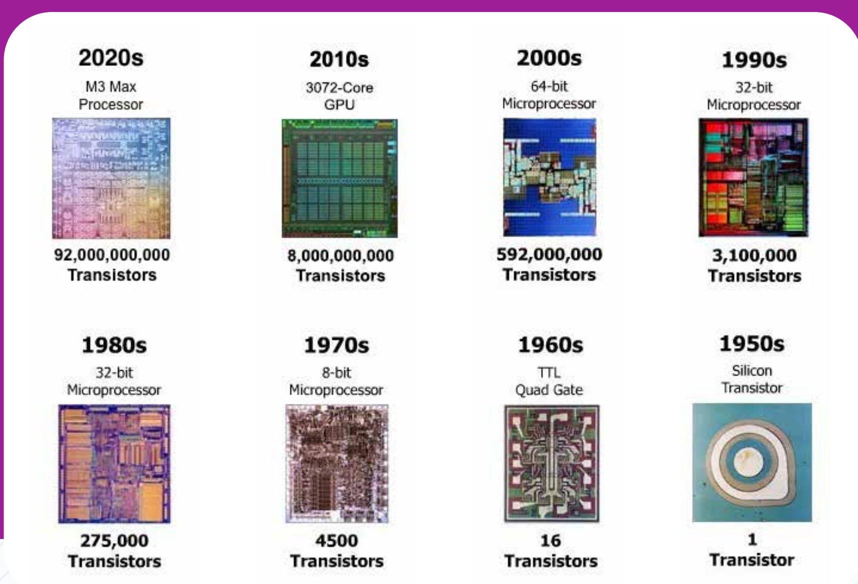
Yield

Determine the yield. How many chips can you get out of your wafer? Typically, a wafer with approximately a 12-inch diameter can **yield** 300-400 chips, depending on the amount of space between them.

The size of the semiconductor chip! These chips are on a nanoscale. Nanoscale is incredibly small – a billion times smaller than what we can see with our eyes! Your fingernails grow about a nanometer every second, or 86,400 nanometres in a day, yet that's way too small for you to notice the growth.

WATCH the Zoom into a Microchip video by NISENet

In addition to making the chips smaller, researchers are constantly looking for new ways to increase the size of the wafer in order to increase the number of chips that can be cut from a wafer. **Wafers can range widely** in size, from 25 mm to 450 mm. Find out your chip's scale factor. What is the ratio of your Play-Doh wafer to a real wafer (3 inches in diameter, or 76 mm in diameter)? What is the ratio of your Play-Doh wafer to a 25 mm chip?



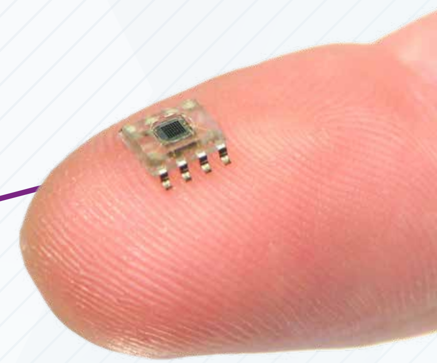
NANOSCALE MISSION:

Moore's Law

Take on the role of a mathematician.

GRAPH: Take the information from the transistor graphic. Create a graph showing how the transistor count has changed. Discuss the exponential growth pattern and its implications.

THINK: Predict what computers might look like in the next decade based on this trend and imagine the features of a computer or smartphone in the year 2030.

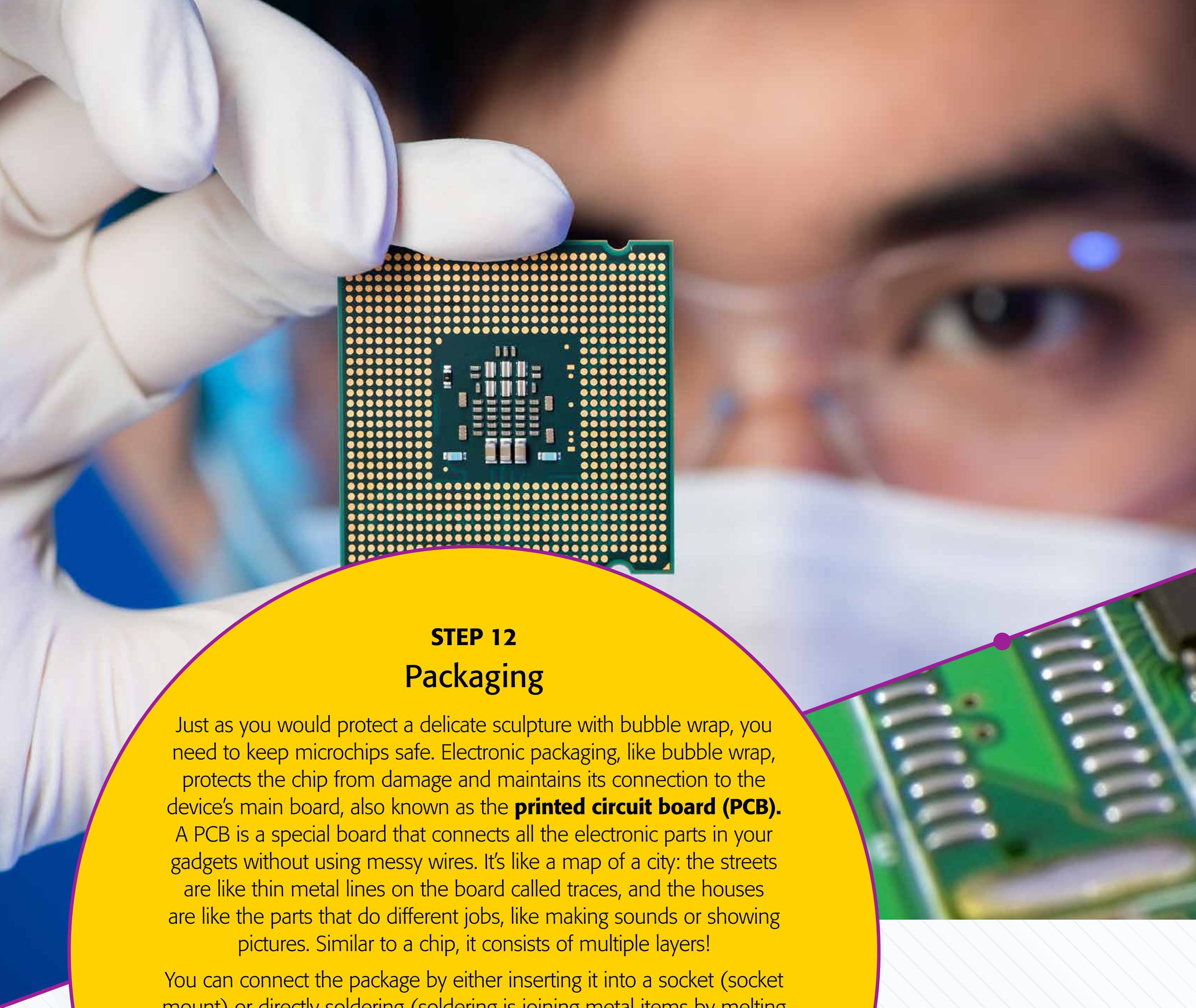


There are millions of transistors on this chip and billions of transistors in your cell phone.

Moore's Law is like a growth spurt for computers! Gordon Moore, the co-founder of Fairchild Semiconductor and Intel, predicted in 1975 that the number of transistors (tiny switches) on a microchip would double about every two years. That means the chips get smaller and smaller. Imagine it's like your room getting twice as big every two years. This growth helps make computers faster and more powerful. Amazingly, Moore's Law has proven to be true for the last 50 years.

Image Source: https://www.computerhistory.org/siliconengine/

Think & Calculate: Count the number of LEDs you got to light up; this is your yield. What could you do differently to increase your yield? When quality control tests your chips, they will close the circuit (using batteries and wires), and if it lights up, it counts toward your yield. If you have 7 chips and 6 light up during testing, your yield will be 6 out of 7, or 86%. The goal is to have a yield of 100%. Calculate your yield.



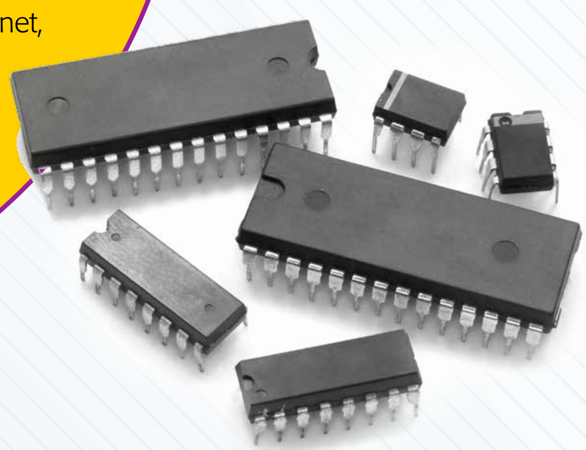
STEP 12

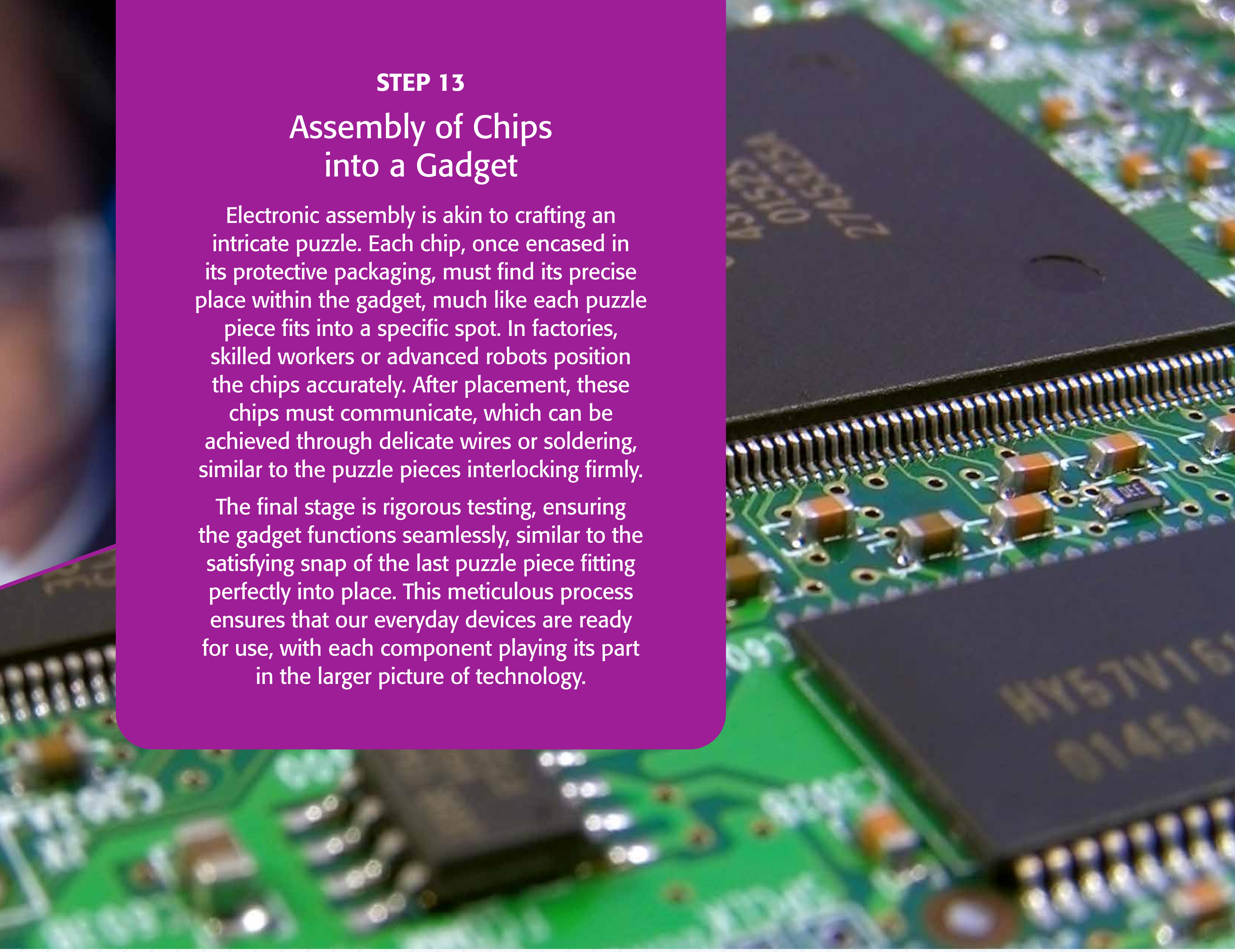
Packaging

Just as you would protect a delicate sculpture with bubble wrap, you need to keep microchips safe. Electronic packaging, like bubble wrap, protects the chip from damage and maintains its connection to the device's main board, also known as the **printed circuit board (PCB).** A PCB is a special board that connects all the electronic parts in your gadgets without using messy wires. It's like a map of a city: the streets are like thin metal lines on the board called traces, and the houses are like the parts that do different jobs, like making sounds or showing pictures. Similar to a chip, it consists of multiple layers!

You can connect the package by either inserting it into a socket (socket mount) or directly soldering (soldering is joining metal items by melting a filler metal (called solder) at the joint where they meet) it to the board's surface (surface mount). This packaging is essentially a sturdy little case for the chip, complete with a network of fine wires and connections. These connections are like the chip's own mini-internet, allowing it to communicate with other parts of the device, ensuring everything works together seamlessly.

THINK: What kinds of material do you think the packaging is made of, and why? Research to confirm.





STEP 13

Assembly of Chips into a Gadget

Electronic assembly is akin to crafting an intricate puzzle. Each chip, once encased in its protective packaging, must find its precise place within the gadget, much like each puzzle piece fits into a specific spot. In factories, skilled workers or advanced robots position the chips accurately. After placement, these chips must communicate, which can be achieved through delicate wires or soldering, similar to the puzzle pieces interlocking firmly.

The final stage is rigorous testing, ensuring the gadget functions seamlessly, similar to the satisfying snap of the last puzzle piece fitting perfectly into place. This meticulous process ensures that our everyday devices are ready for use, with each component playing its part in the larger picture of technology.

WATCH two short videos to **learn more about the semiconductor industry and packaging.**

HISTORY MISSION:
Transistor Revolution

Take on the role of a Technology Historian. Hold a debate on the statement: "The invention of the transistor is the most significant technological advancement of the 20th century."

Let's Review the History of the Semiconductor Industry

The Transistor Revolution

In 1947, scientists at Bell Labs invented the transistor, a tiny electronic component made from semiconductors. Transistors replaced bulky vacuum tubes and revolutionized electronics. They're the building blocks of modern devices like computers, phones, and televisions.

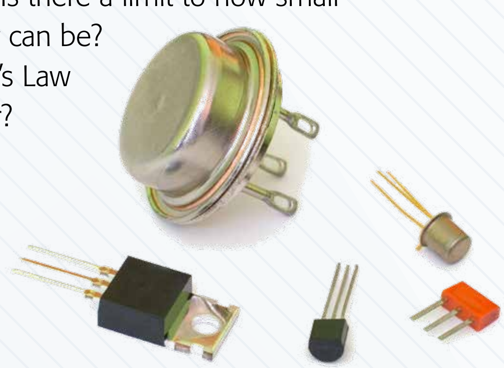
So, what is a transistor? Transistors act as switches. When a small amount of current flows into one part of the transistor (called the gate), it allows a larger current to flow through another part (the drain). This switching capability is essential for microprocessors.

WATCH this video [Transistors: Teeny Tech that Changed the World] by Abby Kent (Project for Science and Natural History Filmmaking from Montana State University) to learn more.

Source: https://kids.britannica.com/students/article/integrated-circuit/603797
https://kids.britannica.com/students/article/transistor/277411

In the early 1960s, the invention of the integrated circuit (commonly known as a microchip) extended the capabilities of the single transistor. To compile an integrated circuit, many transistors are manufactured at once and permanently connected within a single silicon chip. In the past 50 years, the number of transistors on a chip has grown to more than one million on a single chip.

THINK: How much smaller can a transistor be? In 10 years, how many might fit on the tip of an eraser? Is there a limit to how small a transistor can be? Will Moore's Law last forever?



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Careers *in* Semiconductor Industry

As you saw in the video, there are so many diverse careers in the semiconductor industry! **Review** the graphic of semiconductor careers **and engineering disciplines. Many engineers have the skills and knowledge to perform multiple functions.**

REFLECT: What job seemed most interesting to you?

Software
Software Architect
CAD Engineer
Computer Programmer

Design
Computer Architect
Design Engineer
Layout Engineer
Verification Engineer
Layout Technician

Equipment
Systems Designer
Optical Engineer/Designer
Equipment Technician
Service Engineer

Materials
Materials Engineer
Metrology Specialist
Test Engineer/Technician

Wafer Processing
Semiconductor Scientist
Semiconductor Process Engineer
Equipment Technician
Service Technician
Wafer Test Engineer
Metrology Engineer/Technician

Packaging
Packaging Process Engineer
Equipment Technician
Service Technician
Test Engineer/Technician

Assembly
Systems Designer
Equipment Technician
Service Technician
Test *Automation* ***Engineer/Technician***

STEM Career Paths/Discipline Key

- Electrical Engineering
- Computer Science
- Computer
- Mechanical Engineering
- Physical Sciences (Physics, Chemistry)
- Chemical Engineering

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What is the Semiconductor Supply Chain?

Supply chains are like intricate webs connecting factories, warehouses, trucks, ships, and stores. They ensure that products—whether it's the latest smartphone, a trendy fashion item, or a beloved toy—reach us efficiently. But what happens when we disrupt this delicate balance? Let's explore some common causes:

Natural Disasters: Mother Nature can be fierce. Earthquakes, hurricanes, floods, or wildfires wreak havoc on roads, factories, and shipping routes. Imagine a toy factory in a flood-hit area—production stalls and toys can't make their way to stores.

Transportation Delays: Trucks break down, ships get stuck in canals, and planes face delays. These glitches ripple through the supply chain. Delays in a crucial shipment of silicon chips for phones impact phone production globally.

Global Demand Surges: Picture the latest gaming console hitting the market. Everyone wants it! But factories can only produce so many at once. When demand outpaces supply, shortages occur. Suddenly, getting your hands on that console becomes a quest.

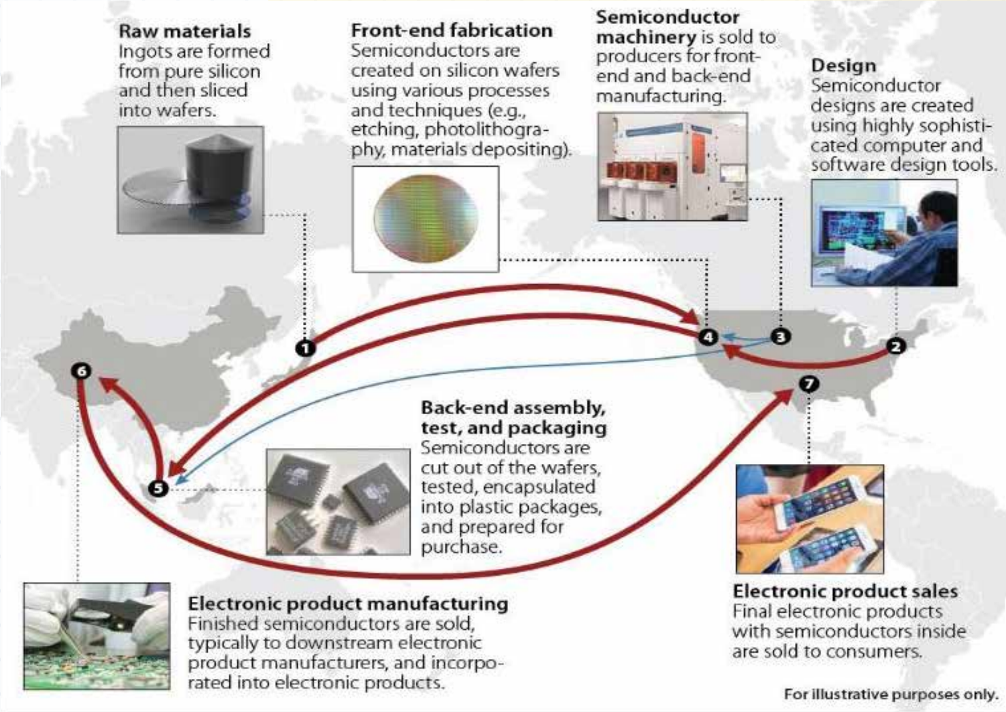
Labor Shortages: Factories need skilled workers. If people fall sick or can't work due to health crises (like the recent pandemic), production slows down. Fewer workers mean fewer toys, gadgets, and gizmos.

Geopolitical Tensions: Countries trade with each other, but sometimes politics gets in the way. Tariffs, trade disputes, or sanctions disrupt the smooth flow of goods. Imagine a toy made in Country A, assembled in Country B, and shipped to Country C—any tension between these nations affects the process.

Supplier Woes: A foundry relies on raw materials like silicon, gallium, gold, and even iridium (which is even rarer than gold!). If a storm wipes out an iridium mine, the entire industry suffers. Suddenly, phones, game consoles, and electronic toys become scarce. The supply chain is only as strong as its weakest link.

SUPPLY CHAIN MISSION:
Science Fiction Saga

Read the Silicon Valley Saga.
As a class, team, or individually, write a short story about a particular supply chain disruption and how it impacted the world.



Source: CRS, adapted from information provided by SIA, https://www.commerce.gov/news/blog/2022/01/results-semiconductor-supply-chain-request-information

Just-in-Time Inventory: Many companies keep minimal stock—they order just what they need when they need it. It's efficient, but risky. If a single supplier falters, the whole chain stumbles. Imagine dominoes falling.

In the end, supply chains are complex systems, akin to a well-choreographed dance amidst chaos. Each disruption creates ripples that affect our lives. As you unbox a new gadget or toy, think of the intricate journey it took to reach you. It's a testament to the steadfast dedication of those who maintain the flow of goods, despite the challenges of nature and circumstance.

Supply Chain Crisis

Imagine a serious supply chain disruption: A cataclysmic storm hits the world's biggest silicon mines, and now they all lie buried. This scarcity disrupts the production of phones, game consoles, and toys, and disables our foundries. Society grapples with the absence of everyday electronics, underscoring the critical role of the semiconductor supply chain in our interconnected lives.

THINK: What would you do?

What creative solutions could you come up with during a supply chain disruption?

Brainstorm ideas like local production, **alternative materials,** or community support. How can we adapt when faced with scarcity?

If you led a toy company during a supply chain crisis, what decisions would you make?

Consider balancing demand, communicating with customers, and finding alternative suppliers. How would you keep the business running?

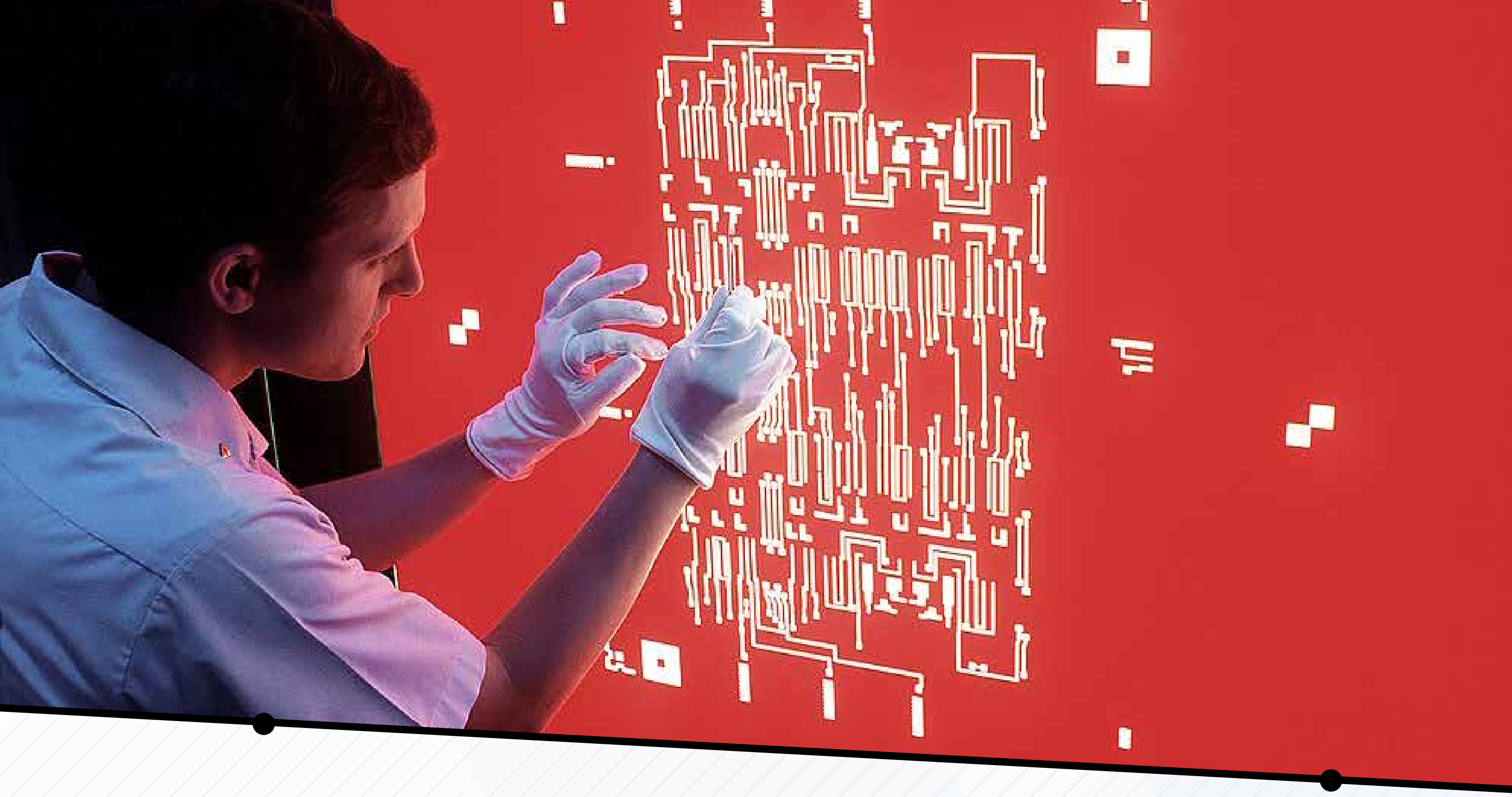
The Future

As chips get smaller and smaller, **we will have "smart" everything!** Did you know that, thanks to semiconductors, we even have smart sneakers?

Sensors in smart sneakers and other smart devices typically contain a microchip. This microchip processes the data collected by the sensor, such as pressure or motion, and then communicates that information to other devices, like your smartphone or computer. The microchip allows the sensor to be "smart" by enabling it to analyze and transmit data, making it useful for tracking and improving performance in activities like running. By connecting devices together through networks like the internet, semiconductors can make your shoe tell your phone how far you ran, or tell a trainer how you might be able to improve your stride.

Image Source: Nike AdaptSource: Nike Inc.

THINK: What other everyday items would you like to see become "smart"? How do you think semiconductors will change in the next 50 years, and what new devices might we use?



Tiny Tapeout (Next Step!)

Make Your Very Own Chip!

If you loved the design mission of taking on the role of the integrated circuit designer, consider the next step of actually making a real chip with Tiny Tapeout. Tiny Tapeout is an educational project that makes it easier and cheaper than ever to get your designs manufactured on a real chip! Explore Tiny Tape Out.

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Learn more at tryengineering.org/semiconductors

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