Learning About Semiconductor Technology

PHOTOLITHOGRAPHY

HIGH SCHOOL CHEMISTRY
HIGH SCHOOL PHYSICS

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Photolithography

Lesson Overview	Career Highlight
Students will learn how computer chips get transformed from a brick of processed material into the items we associate with electronic devices, specifically by addressing the aspect of Photolithography, or the method of stenciling complex designs into silicon wafers.	Manufacturing Engineer Chemist

STEM Course Connections	21st Century Skills	CTE Alignment
High School Chemistry High School Physics	Critical Thinking Collaboration	Manufacturing and Product Design

Engineering Activity	
Science and Engineering Practice #	Students will understand the basic principles of developing microchips and will be able to perform a simple photolithography experiment in a lab setting.

Materials

- Beakers
- Circuit board
- Clothespins
- Clothing Line
- Eye protection
- Gloves
- Iron(III) chloride solution
- Paperclips
- Permanent Markers
- Photomasks (circuit board patterns on acetate sheets) x 2
- Photoresist developer applicators x 10
- Photoresist stripper applicators x 10
- Photosensitive paper
- Semiconductor Case Studies
- Transparent film (projector sheets)
- Tweezers with a small rubber band
- UV light box

Essential Questions

1. How are circuit boards created?
2. Why are precision and accuracy important in photolithography?

Prerequisite Knowledge

Students should have a basic knowledge of what a microchip is, and the uses for microchips within the semiconductor industry. Recommended HTU lessons include: Introduction to Semiconductors; What are Semiconductors?; Education and Career Pathways; Semiconductor Industry Introduction + Pathways

Engage

What is a Photomask? (10 mins)

- Students will watch a video about Photomasks and will answer the following questions on Section A of the Student Handout.
  - What is a photomask? *A template used to print circuitry on a silicon wafer.*
  - How long does it take to create a new photomask? *Approximately five days.*
  - What is the purpose of the lens in a photolithography machine? *To focus the image from the photomask onto the surface of the wafer.*
- Have students share their responses.

Explore

Sun Photography (20 mins)

- Students will each be given one piece of photosensitive paper (covered), two paper clips, a permanent marker, and a transparent film.
- Keeping the photosensitive paper covered, students will make a simple design on the transparent film using the permanent marker. It can be as simple as writing their name on the sheet.
- The teacher will then turn the lights in the classroom off to limit exposure to the photosensitive paper. They will take the photosensitive paper, place it shiny side up on the table, and layer the transparent film on top. They will then use the paper clips to keep both in place.
- Once all students have completed this step, have all of the students bring their photosensitive paper/film combinations outside and leave them in the sun. *Teacher Note: On a sunny day, the paper should be exposed to sunlight for approximately five minutes. On a cloudy day, it should be exposed for approximately 15 minutes. In that time, it is imperative that the film on top of the paper does not move.*
- **Predict -** What will happen to the photosensitive paper? Students will make their prediction on Section B of the Student Handout. Share predictions with a partner. *Students may predict that the photosensitive paper will darken, except for where it is covered by the shadow provided by the permanent marker.*
- **Observe -** Students will watch as over the course of several minutes, the photosensitive paper begins to darken. Students will take notes on their observations in Section B of the Student Handout.
  - Once the paper has changed color significantly enough that the photomask effect is apparent, have the students bring their sheets inside, remove the transparent film, and submerge the photosensitive paper in water for approximately one minute.
  - The paper can then be hung to dry on a clothing line or elsewhere.

- **Explain -** Teacher will explain that the Ultraviolet rays from the sun caused a reaction within the photosensitive layer which was blocked by the permanent marker, and that submerging the photosensitive paper in water halted the process from continuing. Students will summarize this explanation in Section B of the Student Handout.
- **Reflect** - Students will answer the following question in Section B of the Student Handout. Based on the demonstration, what conclusions can you draw about the photolithography process? *The photomask is intended to transfer a complex design onto a substrate (or wafer).*

Understanding Ultraviolet Rays (20 mins)

- Students will watch a brief video explaining Extreme UltraViolet Lithography, and then answer the following questions in Section C of the Student Handout.
  - What is the acronym EUV short for? *Extreme Ultraviolet Lithography System.*
  - What is the purpose of EUV Lithography? *By using Ultraviolet light, which has shorter wavelengths than visible light, computer chip manufacturers are able to develop chips with the smallest transistors possible.*
  - How is Extreme Ultraviolet radiation created? *A high-powered laser is fired at microscopic droplets of Tin, releasing EUV radiation that is captured by mirrors and directed at the silicon wafer.*

Explain

Silicon Chips (10 mins)

- Students will watch a video about Silicon Chips and Wafers and answer questions in Section D of the Student Handout:
  - What are silicon chips? *Silicon chips are the basic components that make up our phones, electronics, and all other technological devices.*
  - What are silicon wafers? *Silicon wafers are thinly-sliced discs of ultrapure silicon usually 12 inches in diameter.*
  - What are silicon wafers used for? *Silicon wafers are used to create many microchips at the same time using a variety of manufacturing practices.*

Photolithography Explained (15 mins)

- Students will watch a brief video explaining the process of Photolithography, and then answer the following questions about the process in Section E of the Student Handout.
  - What is the purpose of Photolithography? *To imprint a pattern onto a Silicon chip.*
  - What is a Photomask, and what is its purpose? *A photomask is a transparent screen that contains a pattern or design that will be transferred to a Silicon wafer.*
  - What is the name of the chemical layer closest to the photomask during the photolithography process? *Photoresist*
- Students share their answers with the class.

Academic Vocabulary Development (15 mins)

- In pairs, students will develop their academic vocabulary in Section F of the Student Handout.

Elaborate

Photoresist Lab (60 mins)

- *Teacher Note: This portion of the lesson requires materials that may not be readily available in a high school science laboratory. Resources may be available at a nearby college or community college, or may be purchased through a grant or crowd-funding. If resources and funding are not available, move on to the Evaluate section.*
- Students will work through this lab in small groups of three or four.
- Each group will receive a piece of circuit board that has black tape covering the side protecting the photoresist layer from the light. Students should be careful not to get fingerprints on the board. Students will carefully peel off the black tape to reveal the photoresist.
- Students will place the circuit board over one of the patterns on the photomask, photoresist side down.
- When all the circuit boards are ready, the light box should be turned on for 80 seconds.
- After the UV exposure has ended and the light box has been turned off, students should retrieve their circuit board. There should be a faint pattern in the photoresist on the circuit board. The exposed photoresist will have a slightly more yellow color than the unexposed region, which appears metallic green.
- Students should gently dab on the developer (do not rub) using the applicator sponge. Cover the entire photoresist surface, including the edges. The developer will remove the exposed photoresist.
- As soon as the shiny copper is exposed, rinse off the developed photoresist with water to reveal the copper underneath.
- Students should use the tweezers to pick up the developed circuit board, being careful not to touch the photoresist pattern. Set a timer for 10 minutes.
- Teacher will dip the circuit board into the iron(III) chloride solution to etch the board. Make sure that the entire board is covered. Gently swirl the solution occasionally.
- After 10 minutes, students will start checking the board to see if etching is complete. Remove the circuit board and dip it into clean water in a plastic tray. Look to see if the copper that is not protected by the photoresist is completely etched away, revealing the plastic underneath. If the copper is not completely etched, place the board back into the solution.
- When etching is complete, wash the circuit board in clean running water.
- Dab on the photoresist stripper to dissolve the photoresist that is covering the copper pattern.
- Rinse with running water.
- The copper pattern should appear shiny and metallic.
- After the lab, students should answer the following questions in Section G of the Student Handout.
    - What are some of the sources of error in the photolithographic process? *Misalignment of mask to substrate, over/under exposure, over/under etching etc. Each step is very sensitive and must be done carefully.*
    - What are the limitations that determine the minimum sized feature that can be produced by photolithography? *The photoresist is patterned by UV light. Features cannot be smaller than the wavelength of light (365 nm) unless some optical 'tricks' are played. For smaller features, electron beams are used to pattern photoresists.*
    - Other than increased processing speed, what are the advantages of making chips smaller? *Increased portability, parallel processing (lower production costs), lower material costs, greater durability.*

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Evaluate

Semiconductor Case Study (45 mins)

- Students will split into groups of five.
- Students will be assigned one of five case studies about semiconductors, involving Global Positioning Satellites, the automotive industry, the medical device industry, the defense industry, and consumer electronics.
- Students will each read their respective case study, and answer the following questions in Section H of the Student Handout about them.
    - What is an example of a product within this field that utilizes a semiconductor-based microchip?
        - i. *GPS Satellites themselves*
        - ii. *Computers that run CNC machines*
        - iii. *Imaging machines*
        - iv. *Drone computing hardware*
        - v. *A cell phone*
    - Why do devices within this case study require semiconductor-based microchips? *All of these fields of technology require advanced computing systems that require the use of semiconductor-based microchips.*
    - What is a functionality of a semiconductor-based microchip that would be critical to this particular discipline?
        - i. *Communicating with a satellite in orbit to find an exact geographic position.*
        - ii. *Computers need to be able to control assembly equipment to within very small tolerances.*
        - iii. *A great deal of processing power must go into the drafting programs that create medical devices.*
        - iv. *Military hardware requires a lot of computing in order to operate equipment safely and effectively.*
        - v. *We can't see memes on our phones without microchips.*
- Students will then present their topic to the rest of their group. They will then answer the following questions in Section H of the Student Handout as a group.
    - How do improvements in semiconductor development collectively affect each of these fields? *By improving the quality of microchips, we can continue to create smaller and more efficient end products that will provide better end-products for each field.*
    - Which of the fields did your group seem to already know the most about, and why? *Answers will vary.*

Extend

Students can participate in the Microchips and Solar Chips lesson.

CA NGSS Standards

HS-PS4-4. Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter.

CTE Alignment

11.4 Employ entrepreneurial practices and behaviors appropriate to Manufacturing and Product Design sector opportunities.
B11.0 Understand and defend the purposes and processes of inspection and quality control in machining and forming processes.
D1.0 Understand the basic product design and development process as it relates to the design of a product, line of products, system design, or services.
D5.0 Develop the concept into a well-defined product for prototyping.
D6.0 Produce a prototype of a product.

Resources

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Name		Date	

Photolithography Student Handout

Directions: Students read the prompts and answer in complete sentences in the box to the right.

Engage:

Section A: What is a Photomask?	
Watch the video about Photomasks, and answer the following questions.	
What is a Photomask?	
How long does it take to create a new photomask?	
What is the purpose of the lens in a photolithography machine?	

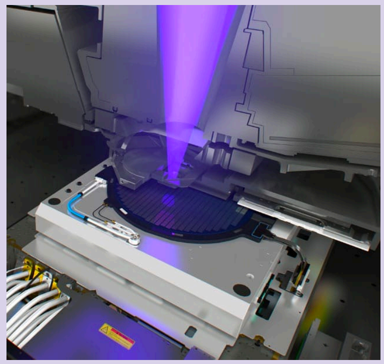
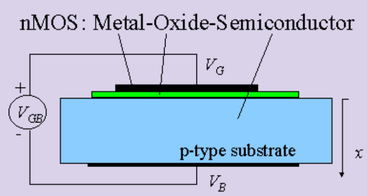
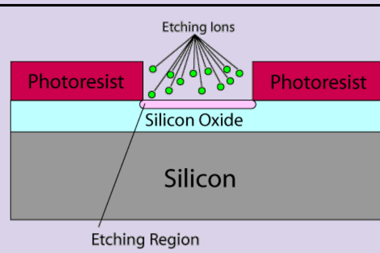
Explore:

Section B: Sun Photography	
Predict: What will happen to the photosensitive paper?	
Observe: What do you notice about your photosensitive paper throughout the process?	
Discuss: In your own words, describe what occurred during the demonstration.	

Reflect: Based upon the demonstration you just received, what conclusions can you draw about the photolithography process?	
Section C: Understanding Ultraviolet Rays	
Watch the video about Extreme Ultraviolet Radiation, and answer the following questions.	
What is the acronym EUV short for?	
What is the purpose of EUV Lithography?	
How is Extreme Ultraviolet radiation created?	

Explain:

Section D: Silicon Wafers	
Watch the video about Silicon chips and wafers, and answer the following questions.	
What are silicon chips?	
What are silicon wafers?	
What are silicon wafers used for?	
Section E: Photolithography Explained	
Watch the video explaining the process of Photolithography, and answer the following questions.	
What is the purpose of Photolithography?	
What is a Photomask, and what is its purpose?	

<table>
<tr><td colspan="2">What is the name of the chemical layer closest to the photomask during the photolithography process?</td><td colspan="2"></td></tr>
<tr><td colspan="4">Section F: Academic Vocabulary</td></tr>
<tr><th>Word</th><th>Definition</th><th>Image</th><th>Description in Own Words</th></tr>
<tr><td>Photolitho-graphy</td><td>Lithography method that uses light to print a pattern in a photosensitive material.</td><td></td><td></td></tr>
<tr><td>Substrate</td><td>The film stack, including the wafer, on which the resist is coated.</td><td>
</td><td></td></tr>
<tr><td>Photoresist</td><td>A photosensitive material that forms a three-dimensional relief image by exposure to light and allows the transfer of the image into the underlying substrate</td><td></td><td></td></tr>
<tr><td>Etching</td><td>the process of selectively removing material from a substrate using a chemical reaction. This is typically done after a layer of photosensitive material, such as photoresist, has been applied to the substrate and exposed to light through a mask or patterned template.</td><td>
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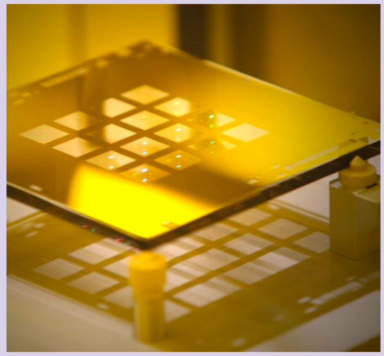
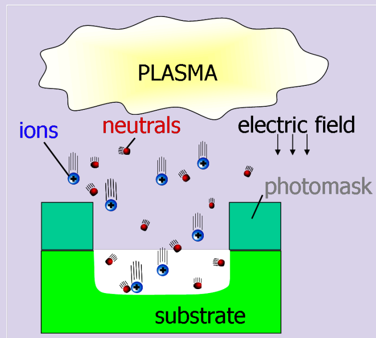
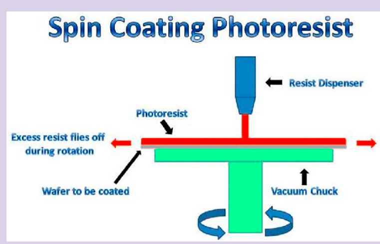
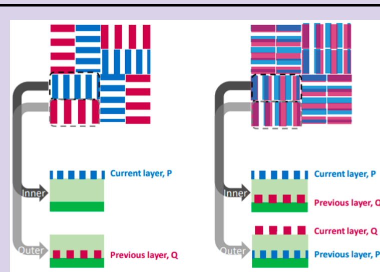
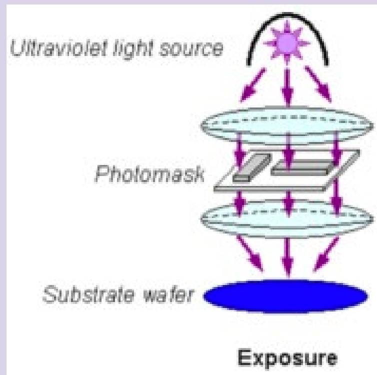
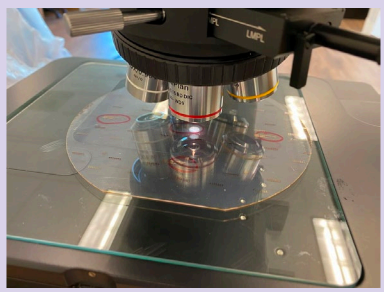
</table>

Photomask	a high-precision plate or film containing a patterned array of transparent and opaque areas used in photolithography to transfer patterns onto substrates.		
Dry Etching	a process of selectively removing material from a substrate using plasma or reactive ions, without the use of a liquid chemical solution.		
Wet Etching	a process of selectively removing material from a substrate by immersing it in a liquid chemical solution that dissolves the material to be etched.		
Spin coating	A process of depositing a thin layer of photoresist onto a substrate using centrifugal force.		
Overlay	The process of aligning multiple patterns on a substrate to create a final device or circuit.		

Development	The process of selectively removing either the exposed or unexposed regions of the photoresist after exposure.		
Exposure	The process of shining light onto a photoresist-coated substrate through a mask to create a pattern.		
Resolution	The smallest feature size that can be reliably transferred using a particular lithography process.		

<u>Elaborate:</u>

Section G: Photoresist Lab	
After completing the Photoresist lab as a class, answer the following questions.	
What are some of the sources of error in the photolithographic process?	
What are the limitations that determine the minimum sized feature that can be produced by photolithography?	
Other than increased processing speed, what are the advantages of making chips smaller?	

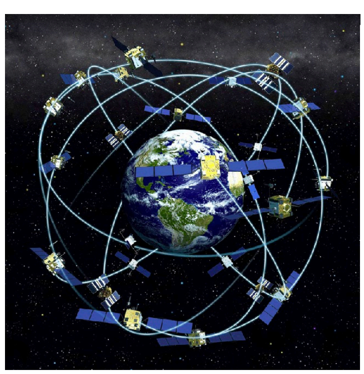
Section H: Case Study	
Read your case study individually, and answer the following questions.	
What is an example of a product within this field that utilizes a semiconductor-based microchip?	
Why do devices within this case study require semiconductor-based microchips?	
What is a functionality of a semiconductor-based microchip that would be critical to this particular discipline?	
Once you have completed presenting your case study, answer the remaining questions with your group.	
How do improvements in semiconductor development collectively affect each of these fields?	
Which of the fields did your group seem to already know the most about, and why?	

Case Study 1: Global Positioning Satellites

Silicon semiconductors are essential components in Global Positioning Systems (GPS) both in the satellites and the end-user devices. GPS is a satellite-based navigation system that uses a network of orbiting satellites to determine the precise location of a device on Earth. Each GPS satellite is equipped with an atomic clock and transmits signals that contain the time and the satellite's location. The signals are received by GPS receivers on the ground or in the air, which use the information to calculate the user's position, speed, and direction of travel.

The GPS satellites use silicon semiconductors to power their onboard electronics, including the atomic clock and the transmitter. Silicon is a widely used material for semiconductor fabrication due to its excellent electrical and physical properties, including high conductivity, stability, and reliability. The semiconductors in the GPS satellites are responsible for generating and transmitting the signals that are used to calculate the user's position. The semiconductors in the satellites are designed to withstand the harsh conditions of space, including high radiation levels and extreme temperatures.

End-user devices such as smartphones, tablets, and navigation systems also rely on silicon semiconductors for GPS functionality. GPS receivers in these devices use silicon semiconductors to process the signals received from the satellites and calculate the user's position. Silicon semiconductors are also used in the power management and display systems of these devices, allowing for efficient power consumption and high-resolution displays. The widespread availability of GPS-enabled devices has revolutionized many industries, including transportation, logistics, and emergency services, making them more efficient and effective. In conclusion, silicon semiconductors are essential components of GPS technology, allowing for precise positioning, navigation, and communication.




Case Study 2: Automotive

Silicon semiconductors play a critical role in the automotive industry, both in automobiles themselves and in the manufacturing process. In modern automobiles, semiconductors are used for a variety of functions, including power management, safety systems, and entertainment systems. For example, semiconductors are used in the engine control unit (ECU), which manages the engine's performance, fuel efficiency, and emissions. Semiconductors are also used in safety systems such as anti-lock braking systems (ABS), airbags, and traction control systems, helping to improve the safety of the vehicle and its occupants.

Semiconductors are also used in a variety of ways in automobile factories, ranging from automated assembly lines to the control systems used in manufacturing equipment. They are an essential component in the electronic systems used to control robotic arms, conveyor belts, and other machinery used in the manufacturing process. Semiconductors also play a vital role in quality control systems, monitoring and ensuring the accuracy of measurements taken during the manufacturing process. Additionally, semiconductors are used in the electronic systems that monitor and control the flow of materials through the assembly line, ensuring that each part is in the right place at the right time. Overall, semiconductors are critical in the smooth and efficient operation of the complex machinery and systems used in automobile factories.

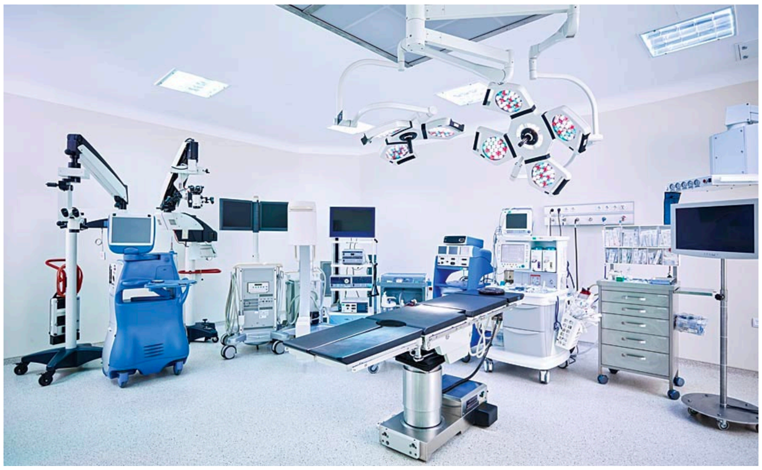
The use of silicon semiconductors in the automotive industry has revolutionized the design and functionality of automobiles. Advanced driver assistance systems (ADAS) such as adaptive cruise control, lane departure warning, and automatic emergency braking are made possible by the use of semiconductors. The automotive industry is also moving towards electric and hybrid vehicles, which rely heavily on semiconductors for power management and control. In conclusion, silicon semiconductors are essential components in the automotive industry, improving the safety, performance, and functionality of automobiles, and enabling the industry to move towards more sustainable and efficient vehicles.

Case Study 3: Healthcare

Silicon semiconductors are increasingly being used in the healthcare field to enable the development of advanced medical devices and equipment. These semiconductors play a crucial role in powering the electronic components used in devices such as pacemakers, defibrillators, and insulin pumps. These devices rely on semiconductors to function correctly, and the high level of precision and reliability provided by these components is essential in ensuring the safety and efficacy of medical treatments.

In addition to powering medical devices, silicon semiconductors are also used in the development of imaging equipment such as MRI machines and CT scanners. These machines use sophisticated electronic systems that rely on semiconductors to generate and process the images used in medical diagnosis and treatment. The high level of precision and speed provided by semiconductors enables these machines to produce accurate and detailed images of the human body, enabling doctors to diagnose and treat a wide range of medical conditions.

Silicon semiconductors are also increasingly being used in the development of wearable medical devices, such as health monitoring watches and fitness trackers. These devices use semiconductors to power the sensors and electronics that enable them to measure a wide range of health and fitness parameters, from heart rate and blood pressure to oxygen saturation and sleep quality. The use of semiconductors in these devices has enabled the development of highly accurate and reliable health monitoring tools, providing patients and healthcare providers with valuable information that can be used to improve health outcomes.



Case Study 4: Defense

Silicon semiconductors play a critical role in the field of national defense, powering the sophisticated electronic systems used in a wide range of military applications. These applications include missile guidance systems, satellite communications, radar systems, and navigation equipment. Semiconductors are used to power the sensors and electronics that enable these systems to function with a high degree of precision and accuracy, enabling military personnel to carry out their missions safely and effectively.

In addition to powering military hardware, semiconductors are also used in the development of cybersecurity systems used to protect national security interests. These systems rely on semiconductors to power the encryption and decryption algorithms used to secure sensitive data and communications, protecting them from interception and unauthorized access. The high level of reliability and security provided by semiconductors is essential in protecting national security interests in an era of increasing cyber threats.

Silicon semiconductors are also used in the development of advanced military drones and unmanned vehicles, providing the electronic systems necessary for autonomous operation. These vehicles are used in a wide range of military applications, including reconnaissance, surveillance, and strike missions. The use of semiconductors in these systems enables high levels of precision and accuracy, ensuring that they can carry out their missions safely and effectively, even in the most challenging of environments.

Case Study 5: Consumer Electronics

Silicon semiconductors are at the heart of nearly all consumer electronics, powering the electronic systems used in smartphones, computers, televisions, and other popular devices. These semiconductors are used to power microprocessors, memory chips, and other electronic components that enable these devices to function with a high level of precision and reliability. The widespread use of semiconductors in consumer electronics has enabled the development of increasingly advanced devices, providing consumers with greater functionality, speed, and convenience.

Semiconductors are also used in the development of audio and video processing systems, providing the electronic components necessary for the high-quality sound and visuals that consumers expect from modern entertainment systems. From the audio processing chips used in high-end headphones to the image processing systems used in 4K televisions, semiconductors are a critical component in the development of consumer electronics that provide an immersive and engaging experience for users.

The use of semiconductors has also enabled the development of wearable electronics, including smartwatches, fitness trackers, and augmented reality headsets. These devices rely on semiconductors to power the sensors and electronics that enable them to monitor health and fitness metrics, track location, and provide users with real-time information and feedback. The use of semiconductors in these devices has enabled the development of highly sophisticated and advanced wearable electronics, providing consumers with a wide range of useful features and capabilities.