Semiconductors and Intel

An introduction
What is a semiconductor?

Semiconductors are essential for the operation of all modern electronic devices.

The semiconductor

The term “semiconductor” refers to a material that has electrical conductivity greater than an “insulator” but less than a “conductor.” However, it more commonly refers to an integrated circuit (IC) or computer chip. The most common semiconductor material is silicon, the main ingredient of computer chips.

Did you know?

Semiconductors are the critical ingredient of computer chips, which are built for many functions. This motherboard is showing at least eight of them (the CPU, chipset, memory, storage, BIOS, and input/output chips).

Functions of semiconductors might include the amplification of signals, switching and energy conversion.
Semiconductors are the foundation of modern technology. Billions of connected devices on the planet would not function without them. Semiconductors are probably the most complex products manufactured in the world, yet they’re often as small as a fingernail. They are packed with billions of microscopic switches, called "transistors," that make them work.

Semiconductors are everywhere

Communications
- Digital cameras
- Radios
- Scanners
- Smartphones
- Televisions
- Watches/clocks

Computing
- Computers/laptops
- XPUs
- Diodes
- Microcontrollers
- RF Transmitters
- Wireless HD video

Consumer/IoT
- ATMs
- Smoke detectors
- Internet
- Refrigerators
- Coffee makers
- Video games
- Washing machines

Healthcare
- Blood-pressure sensors
- Hearing aids
- MRIs
- Pacemakers
- Ultrasound modules
- Wireless patient monitors

Smart Energy
- A/C temp sensors
- Efficient logistics systems
- LED light bulbs
- Monitoring systems
- Security devices
- Smart home systems
- Solar panels

Transportation
- Advanced driver assistance systems
- Diagnostic equipment
- Mapping/Sensing
- Navigation systems

Why are semiconductors so important?

The average American adult spends over 12 hours a day on electronics, such as computers, mobile devices, TVs and cars. Those devices are all powered by semiconductors, which improve our lives, increase productivity and drive economic growth.

Quick tip

The approximate cost to build a new semiconductor factory or “fab”

$10-15B

Nearly the size of the world’s largest semiconductor fab

>6 AMERICAN FOOTBALL FIELDS

The number of construction, high-tech & support jobs a semiconductor fab typically creates

12K

2020 revenue from the global semiconductor industry

+$440B
The exponential computer
From a few in the world to many per person

1960s Mainframe Era
1 computer
1000s of users

1980s Desktop/PC Era
1 computer
1 user

2000s Mobility Era
Several computers
1 user

2020s Ubiquity Era
1000s of computers
1 user
How chips are made

A computer chip’s journey begins with research
Engineers and scientists from companies and academia develop revolutionary processing and packaging technologies

1. Design
Chip architects, logic designers and circuit designers create computerized drawings (blueprints).

2. Mask Ops
Engineers take the digital blueprints and convert them into glass templates, called masks, which are used in fabrication for photolithography, or “printing with light.”

3. Fabrication
Technicians in bunny suits use a multitude of machines to create layers of circuits and devices on silicon wafers. Each wafer will contain hundreds of chips.

4. Die & Sort
Finished wafers get cut into dies (or computer chips) and placed on reels.

5. Test & Assembly
Technicians test each die one last time, then mount them between a heat spreader and a substrate to form a sleek, enclosed package.

6. Warehousing
Logistics professionals ship out chips to customers or global distribution hubs to be sent to manufacturers or boxed up for retail.
Foundries, Intel and IDM 2.0

Typically, semiconductor manufacturers are either:

- **Integrated device manufacturers (IDM)** that design, build and sell their own chips; or
- **Foundries** that build chips for “fabless” customers that design, brand and sell them.

Intel is different. Its **IDM 2.0 strategy** combines:

- Intel’s **internal factory network** to build most of its products.
- The use of **external foundries** for flexibility, scale and cost.
- **Intel Foundry Services**, a new group dedicated to manufacturing for customers.
Moore’s Law and what it means

Moore’s Law was an observation of increasing economic efficiency

In 1965, Gordon Moore made what he later called “a wild extrapolation of very little data” that the number of components per integrated circuit would keep doubling annually (revised later to biannually).

Intel co-founder Gordon Moore

Quick tip

Intel’s first microprocessor, the 4004, had 2,300 transistors in 1971. Today’s have billions. Every process “node” (e.g., 22nm, 14nm, Intel 7, Intel 4) means improvements in power, performance, area and/or other features.
Why are process nodes important?

The result of each new process node can include:

1. Denser components
2. Existing functional blocks (IPs) use less silicon area
3. Many options for better chips:
   - Multiply IPs (more throughput)
   - Add new IPs (new features and capabilities)
   - A smaller overall chip (lower cost)
4. More power-efficient and quicker operation, and/or
5. More dynamic range (efficient at idle, faster at full throttle)

A note on node names: Intel introduced a simple and clear naming structure for its process nodes in 2021, one that no longer refers to nanometers. New names include Intel 7, Intel 4, Intel 3, and Intel 20A, ushering in the angstrom era of semiconductors.
Packaging: protect, connect and re-architect

This Intel processor shows the silicon die at center, which would be attached to the substrate (left) and covered with a heatspreader (right). The combined enclosure is called the “package.” It connects micron-sized features on the die to millimeter-sized features on a computer’s motherboard, protects the die from contaminants, cools it, powers it, and increasingly, allows multiple die to be combined in novel ways.
Packaging: protect, connect and re-architect

New packaging technologies allow the combination of myriad die into “systems in packages,” enabling more design and performance flexibility — leading to entirely new kinds of chips, like the powerful Ponte Vecchio GPU.

Intel is a world leader in advanced packaging development and manufacturing.

Advanced packaging enables new era of chip design

Ponte Vecchio soc

>100 Billion Transistors
47 Active Tiles
5 Process Nodes
Process versus microarchitecture

Think of a chip as a multistory urban building

Microarchitectures are blueprints; they convey what to build

- A **microarchitecture** represents a specific design, a single, unique building. An **architecture** comprises a family of buildings based on a unifying theme.
- Example: Willow Cove and Goldmont are CPU **microarchitectures**; both use Intel Architecture.

Process technologies are construction techniques

- How you take raw materials and create a building.
- Each new **node** is a refinement in process technology — new and better ways to build new and better buildings.

Quick tip

*Chip as tiny skyscraper:* A common chip the size of your smallest fingernail is only around 1 millimeter thick but contains roughly 30 different layers of components and wires (called interconnects) that make up its complex circuitry.
Major processor architectures
What Intel defines as XPU

**CPU**
Central processing unit
(the brain of the computer)

*What do they do:*
Run the computer and all its programs

*Major suppliers:*
Intel, AMD, ARM
(Apple, Qualcomm, Samsung)

**GPU**
Graphics processing unit

*What do they do:*
Make images; accelerate highly parallel operations

*Major suppliers:*
Intel, AMD, Nvidia, ARM, Imagination

**FPGA**
Field-programmable gate array; software-configurable circuits

*What do they do:*
Acceleration, communications, circuit design, applications that change often

*Major suppliers:*
Intel, Xilinx

**ASIC**
Application-specific integrated circuit

*What do they do:*
Do one thing, very quickly: deep learning, encryption, network processing

*Major suppliers:*
Many and varied (including Intel)

Quick tip

**CPU architectures**
X86: mobile device to supercomputer cores from Intel and AMD
ARM: a large span of processors for license or customization
RISC-V: open-source processor design
Modern chips require a lot of software

“For every order of magnitude performance potential from new hardware architecture, there is often more than 2 orders of magnitude unlocked by software.” – Raja Koduri, Accelerated Computing Systems and Graphics (AXG) Group at Intel

<table>
<thead>
<tr>
<th>Developer tools</th>
<th>Services &amp; solutions</th>
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<tbody>
<tr>
<td></td>
<td>Middleware frameworks and runtimes</td>
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<td></td>
<td>Low-level libraries</td>
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<td></td>
<td>Virtualization/orchestration</td>
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<td>Operating system</td>
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<td>Drivers</td>
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<td>Firmware IP &amp; BIOS</td>
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| Hardware: CPU/GPU/AI/FPGA |

Software supplied by Intel for developers and customers
The high cost of manufacturing drives industry consolidation

Staying on the leading edge became unaffordable for all but the three largest companies

2004-06 (90nm)
2010-12 (32/28nm)
2012-14 (22/20/14nm)
2017-20 (10/7nm)

Cost to build a leading-edge fab

$1B
$6B
$10-15B
Semiconductors take a global path to production
And a lot of partnership

As the complexity and number of components in leading-edge chips have increased, so has the amount of time it takes to make them — in some cases more than 3 months.

Intel partners with thousands of innovative companies around the world to bring semiconductors to market, from raw materials to logistics and construction, including:

- Front-end equipment
  - Process equipment
  - Process control
- Front-end materials
  - Materials
  - Silicon
- Back end
  - Assembly equipment
  - Test equipment
  - Substrates
- Design
  - EDA/IP
  - Contract workers
- Other partners
  - Memory
  - Factory construction

Conceptual map flow:
- Fab wafer sorted, cut into die
- Bare wafer into fab wafer
- Consumer buys end product
- Silicon ingots cut into wafers
- Chip integrated into consumer good by end product manufacturer
- Final product shipped for inventory
- Die are assembled, packaged, tested
- Silica ingots cut into wafers
- Consumer buys end product
- Bare wafer into fab wafer
- Fab wafer sorted, cut into die

Quick tip
1. 6 2 3
2. 7
3. 1 5 4
4. 6
5. 5
6. 4
7. 3

Front to back:
- USA to Malaysia
- USA to USA
- Japan to USA
- China to USA
- Singapore to China
Intel’s history in 4 fast eras

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1968-1984</td>
<td>Intel founded with $3M</td>
</tr>
<tr>
<td>1969</td>
<td>First product, first customer</td>
</tr>
<tr>
<td>1971</td>
<td>Microprocessor invented</td>
</tr>
<tr>
<td>1976</td>
<td>Microcontroller invented</td>
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<tr>
<td>1981</td>
<td>IBM puts Intel 8088 in first PC</td>
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<tr>
<td>1983</td>
<td>Intel reaches $1B revenue</td>
</tr>
<tr>
<td>1984</td>
<td>First CHMOS DRAM, up to 64K</td>
</tr>
<tr>
<td>1968-1984</td>
<td>The definitive Silicon Valley startup</td>
</tr>
<tr>
<td>1985-1995</td>
<td>A logical exit from memory</td>
</tr>
<tr>
<td>1985</td>
<td>Intel exits DRAM, debuts 386 processor</td>
</tr>
<tr>
<td>1988</td>
<td>Intel enters flash memory</td>
</tr>
<tr>
<td>1991</td>
<td>Intel Inside logos appear worldwide; Intel breaks supercomputing record</td>
</tr>
<tr>
<td>1992</td>
<td>Intel becomes world’s largest semiconductor company</td>
</tr>
<tr>
<td>1993</td>
<td>Pentium processor</td>
</tr>
<tr>
<td>1995</td>
<td>Pentium Pro launched for servers</td>
</tr>
<tr>
<td>1996-2014</td>
<td>One billion computers</td>
</tr>
<tr>
<td>1997</td>
<td>Iconic bunny people debut in ads</td>
</tr>
<tr>
<td>1998</td>
<td>Intel Celeron debuts</td>
</tr>
<tr>
<td>2000</td>
<td>Pentium 4; revenue surpasses $30B</td>
</tr>
<tr>
<td>2001</td>
<td>First Xeon chips for servers</td>
</tr>
<tr>
<td>2002</td>
<td>Hyperthreading introduced</td>
</tr>
<tr>
<td>2003</td>
<td>Intel Centrino makes Wi-Fi common; Intel ships billionth processor</td>
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<tr>
<td>2005</td>
<td>Multicore processors</td>
</tr>
<tr>
<td>2008</td>
<td>Intel Atom processor</td>
</tr>
<tr>
<td>2011</td>
<td>First 3-D transistor; Thunderbolt introduced</td>
</tr>
<tr>
<td>2013</td>
<td>Intel NUC mini PCs debut</td>
</tr>
<tr>
<td>2015-</td>
<td>XPUs and a new era of data</td>
</tr>
<tr>
<td>2015</td>
<td>$300M diversity and inclusion initiative; Intel acquires Altera</td>
</tr>
<tr>
<td>2016</td>
<td>Silicon photonics ship</td>
</tr>
<tr>
<td>2017</td>
<td>Intel acquires Mobileye; first product with EMIB packaging ships</td>
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<tr>
<td>2018</td>
<td>Employees contribute 1.5M volunteer hours for 50th anniversary;</td>
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<tr>
<td></td>
<td>revenue crosses $70B</td>
</tr>
<tr>
<td>2020</td>
<td>Xe discrete graphics; first 3-D stacked processor</td>
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<tr>
<td>2021</td>
<td>Intel introduces IDM 2.0</td>
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Semiconductors and Intel
Intel invests in future technology and factories to build it

Intel invests in research and development primarily for future process technologies and the PC and data-centric businesses, while also making capital investments in manufacturing and wafer capacity.

**R&D and capital investments**

(in billions)

<table>
<thead>
<tr>
<th>Year</th>
<th>R&amp;D</th>
<th>Logic capital investment</th>
<th>Memory capital investment</th>
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<tbody>
<tr>
<td>2016</td>
<td>$22.3</td>
<td></td>
<td></td>
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<tr>
<td>2017</td>
<td>$24.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2018</td>
<td>$28.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2019</td>
<td>$29.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td>$27.8</td>
<td></td>
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</table>

In the U.S., only the biotech and pharma industry spends more on R&D as a percent of sales than the semiconductor industry.
Intel owns nearly 70,000 active patents worldwide.
Intel invents across an unmatched span of technologies
Intel’s global manufacturing footprint

- Arizona
- New Mexico
- Ireland
- Costa Rica
- Malaysia
- Vietnam
- Chengdu
- Dalian Memory Fab

- Wafer fabs
- Assembly and test
- Intel presence
**Glossary**

**Assembly/test**: The second half of chip manufacturing, where bare silicon die are encased in a protective package and undergo final inspection; also refers to factories dedicated to this function.

**Chip**: A tiny, thin square or rectangle that contains integrated electronic circuitry. A chip contains one or more die, which are built in batches on wafers of silicon.

**Die**: A single integrated circuit cut from a wafer after fabrication.

**Fab**: A factory that performs the first half of silicon chip manufacturing (fabrication), where bare silicon wafers undergo weeks of processing to become integrated circuits.

**Foundry**: A silicon fabrication business (TSMC, Global Foundries) that offers manufacturing as a service to outside chip design companies, which are referred to as “fabless semiconductor companies” (AMD, Nvidia); contrasts with an IDM (Intel, Samsung).

**Integrated circuit**: A semiconductor device that includes many transistors and electrical circuits, designed to perform one or many functions.

**Integrated device manufacturer or IDM**: Company that both designs and manufactures silicon chips, such as Intel and Samsung.

**Intellectual property or IP**: A functional unit of an integrated circuit, such as CPU cores, graphics and media, memory and AI.

**Package**: A protective enclosure around one or many silicon die that includes connectors to the computer.

**Semiconductor**: A material (such as silicon) that can be altered to conduct electrical current or block its passage; common shorthand for computer chips and the industry.

**Transistor**: A type of switch that controls the flow of electricity. A chip can contain millions or billions of transistors.

**Wafer**: A round slice of purified silicon less than 1 mm thick, up to 12 inches or 300 mm in diameter, upon which integrated circuits are implanted and etched and later sliced into individual die.
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