Next generation semiconductor devices and applications

(차세대 반도체 소자 및 응용)

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Applied Nanomaterials & Devices LAB.

Electronics & Probes by Materials Engineering

1. Basic of Semiconductor

Why should we study semiconductor devices?

1. Basic of Semiconductor

Core subject to understand Semiconductor

1. General Chemistry
2. Physics
3. Materials Science and Engineering
4. Semiconductor Physics and Devices
5. Semiconductor Fabrication

The History of Semiconductor

Major Inventions Came with the Growth of Semiconductors

How have semiconductors contributed to the advances in electronics from the 20th century to the present day? The following multifaceted presentation traces the development of technologies that have enriched our lifestyle.

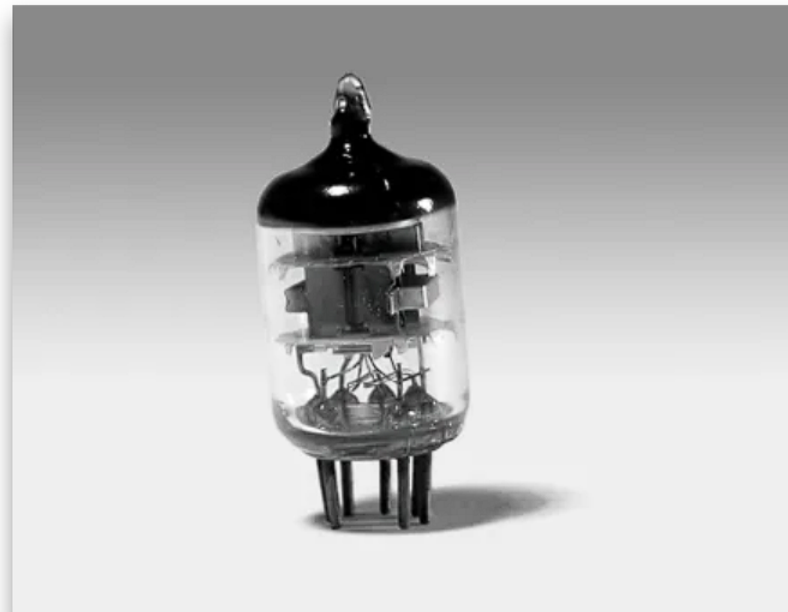
The History of Semiconductor

1904

1904: Two-electrode vacuum tube is invented

Thomas Alva Edison / John Ambrose Fleming

Thomas Alva Edison, the inventor of the first practical incandescent light bulb, had also noticed that the direct electric current flowed from a heated metal filament in the bulb to the other electrode only when the latter had a positive voltage. John Ambrose Fleming used this effect (known as the Edison effect) to invent the two-electrode vacuum tube rectifier, which was soon to play an important role in the electrical circuits.



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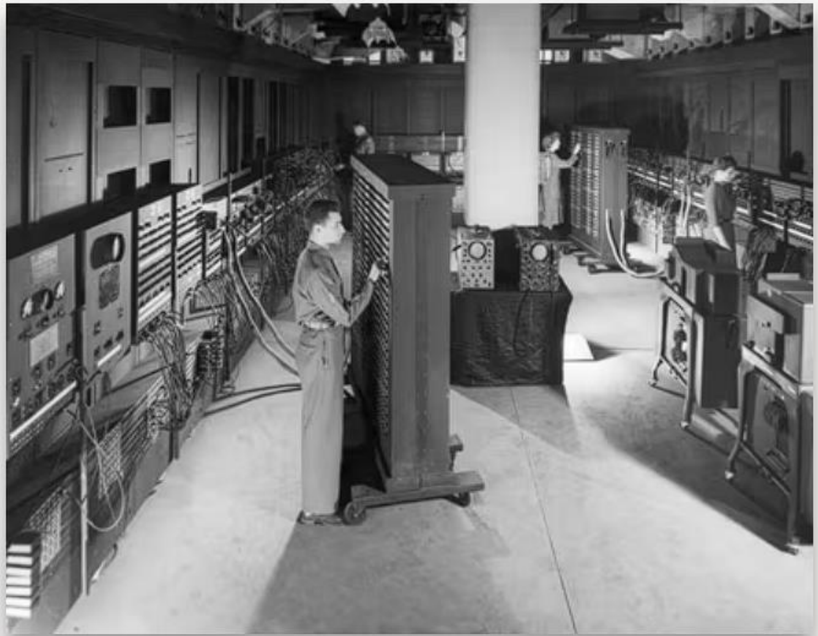
The History of Semiconductor

1946

1946: World's first general-purpose computer ENIAC is announced

ENIAC



ENIAC was the largest electronic machine ever made, equipped with some 18,000 vacuum tubes and weighing about 30 tons. It occupied a 160-square-meter room.
The computer consisted of a total of about 110,000 electronic circuit devices.
In contrast, today's microprocessor typically integrates tens of millions of transistors and yet is smaller than the palm of your hand. This astonishing decrease in size started when solid state semiconductors replaced vacuum tubes.

1948

1948: Junction-type transistor is invented

Transistor / William Bradford Shockley

Toward the end of 1947, John Bardeen and Walter Brattain at AT&T Bell Labs developed the point contact transistor, which was the first transistor ever constructed. William Shockley and his team continued with this research, and announced the invention of the mechanically solid junction-type transistor in June 1948.

Subsequently, integrated circuits (ICs) were invented that packed large numbers of transistors into a small chip, followed by large-scale integrated circuits (LSIs) with an integration level of 1,000-100,000 components or more on a chip.

* The photo is for illustration purposes only

1955

1955: Japan's first transistor radio is released

Transistor Radio / Sony

Early broadcast radio receivers used vacuum tubes. By replacing vacuum tubes with semiconductor transistor devices, radios became smaller, lighter, and less power consuming. Tokyo Tsushin Kogyo (Tokyo Telecommunications Engineering Corporation; now Sony) released Japan's first transistor radio TR-55 in 1955. While attempting to improve the yield of a transistor manufacturing process, the company's research team discovered the quantum mechanical effect known as tunneling.

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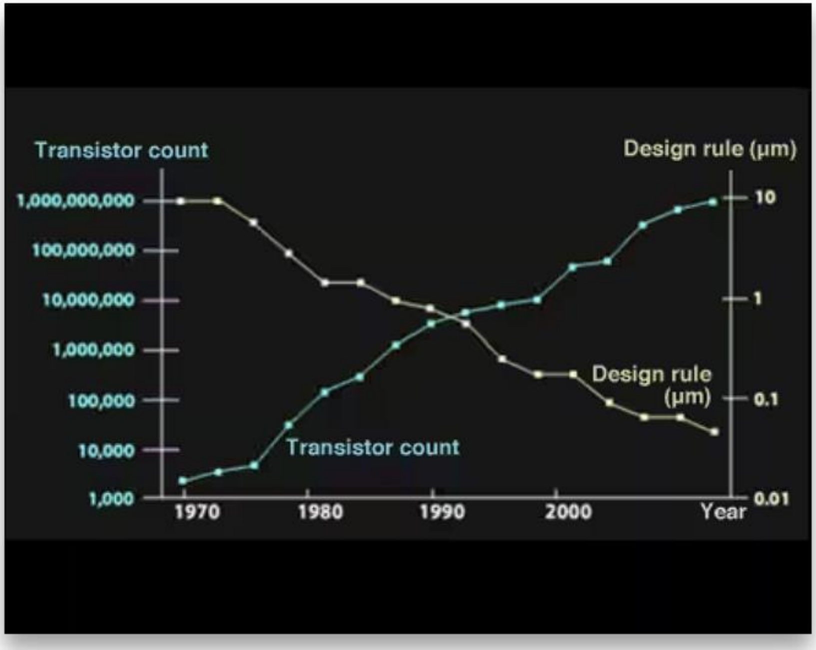
1965

1965: Moore's law is announced

Gordon Moore

In 1965, Gordon Moore (who later became a co-founder of Intel) predicted that the integration rate of LSIs would double every 18 months, implying that it would quadruple in three years and become 1,000-fold denser in 15 years. The prediction, known as Moore's law, was based on the analysis of historical trends in the computer manufacturing industry. The proposition was widely accepted in the semiconductor and computer industries, and the reality turned out to be almost exactly as Moore had foreseen.

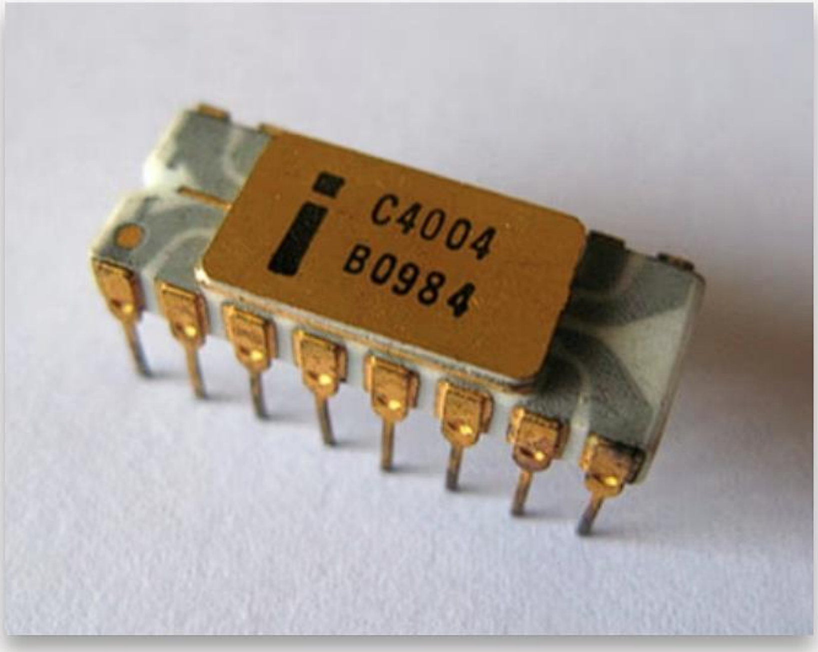


1971

1971: Intel 4004 is released

i4004 / Masatoshi Shima

Intel 4004 was the world's first single chip microprocessor. It was originally developed on the request of Busicom Corporation in Japan as an LSI for its electronic calculator. Intel's Ted Hoff proposed the idea of universal logic processor, which was taken up by Masatoshi Shima at Busicom and Federico Faggin at Intel who completed the chip design. Attracted by the potential versatility of this chip, Intel obtained the sales rights to the product.



* Photo credit: Dentaku Museum

1977

1977: World's first personal computer Apple II is released

Personal Computer / Apple

Although many consider the Altair 8800 to be the world's first personal computer, its manufacturer called it a minicomputer along with other designations such as microcomputer and home computer. In contrast, Apple's Steve Jobs used the term "personal computer," which took hold with the commercial success of the Apple II.

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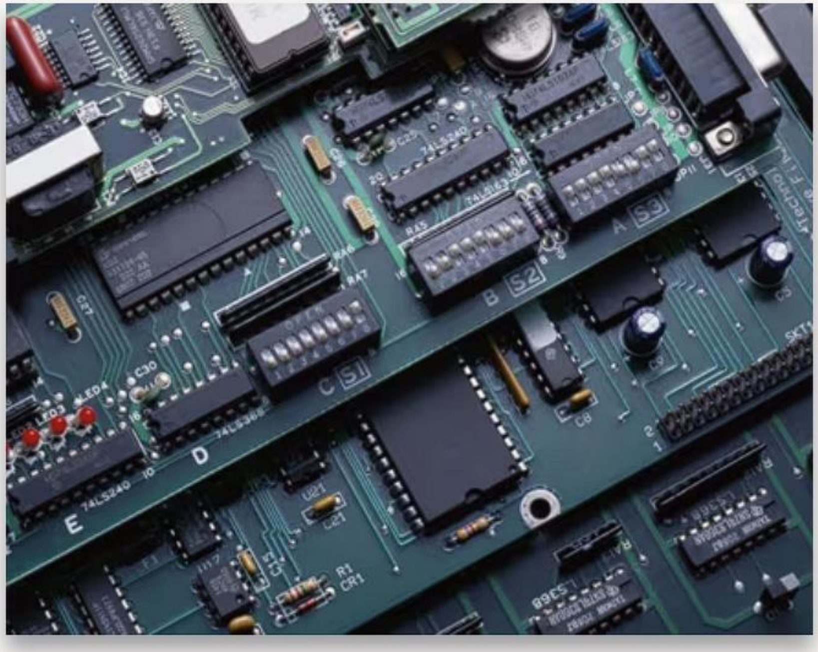
1980

1980: Flash memory is invented

Flash Memory / Fujio Masuoka

Flash memory is a rewritable semiconductor memory device that is non-volatile (i.e., it retains the information when power is turned off). Unlike previous rewritable memory that could only erase the information one byte at a time, flash memory was designed to erase the entire block of data at once, and to reduce the cost per bit by 75% or more.
Flash memory was invented in 1980 by Fujio Masuoka (then a Toshiba employee). Today, flash memory is found in personal computers, mobile phones, digital cameras, IC cards, and many other applications that we use every day.



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1. Basic of Semiconductor

Milestones of Silicon Semiconductor Industry

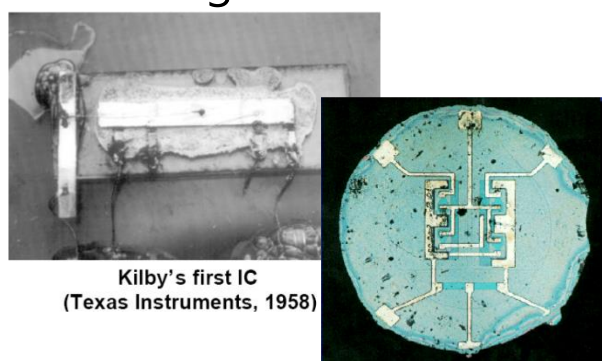
- 1947 : Invention of the Ge transistor at Bell Lab. (Bardeen, Brattain, Shockley)
- 1952 : Production of ultra-pure Si and Ge by zone refining technique at Bell Lab.
- 1955 : Invention of diffusion-based transistor at Bell Lab.
- 1958 : First demonstration of integrated circuit using mesa tech. at Texas Instruments.
- 1959 : Development of IC using planar process at Fairchild.
- 1959 : Invention of the MOSFET at Bell Lab.
- 1960's : Complete the planar process and IC fabrication process.
- 1970's ~ 80's : Market and technology development

First bipolar transistor

First transistor

Nobel Prize (Physics) @1956

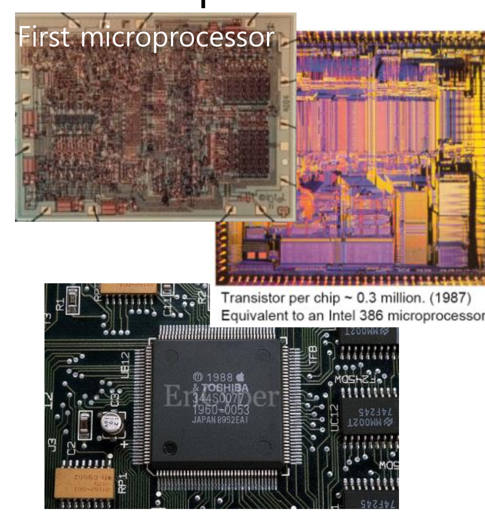
First integrated circuit


Kilby's first IC (Texas Instruments, 1958)

Planar IC invented by Noyce (Fairchild Semiconductor, 1959)

Nobel Prize (Physics) @2000

Microprocessor

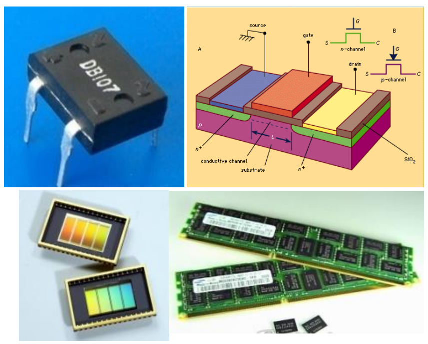


1. Basic of Semiconductor

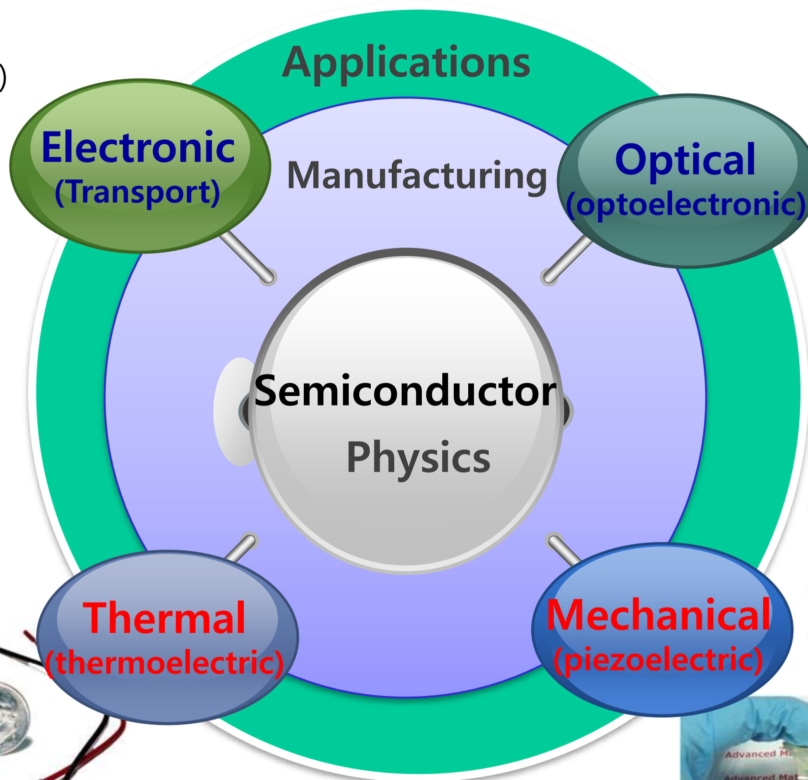
What is semiconductor Technology ?

Semiconductor Technology

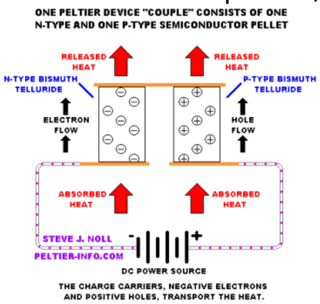
- Diode
  (p-n, Zener, Varactor diodes)
- Transistors
  (bipolar, field effect: MOS, MIS)



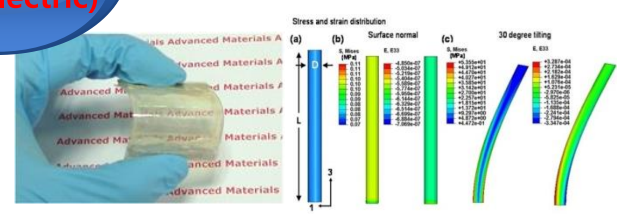
- Light-emitting diode
- Laser diode
- Photodiode
- Solar cell



- Peltier thermal cooler
- Power generator
  (heat to electric power)



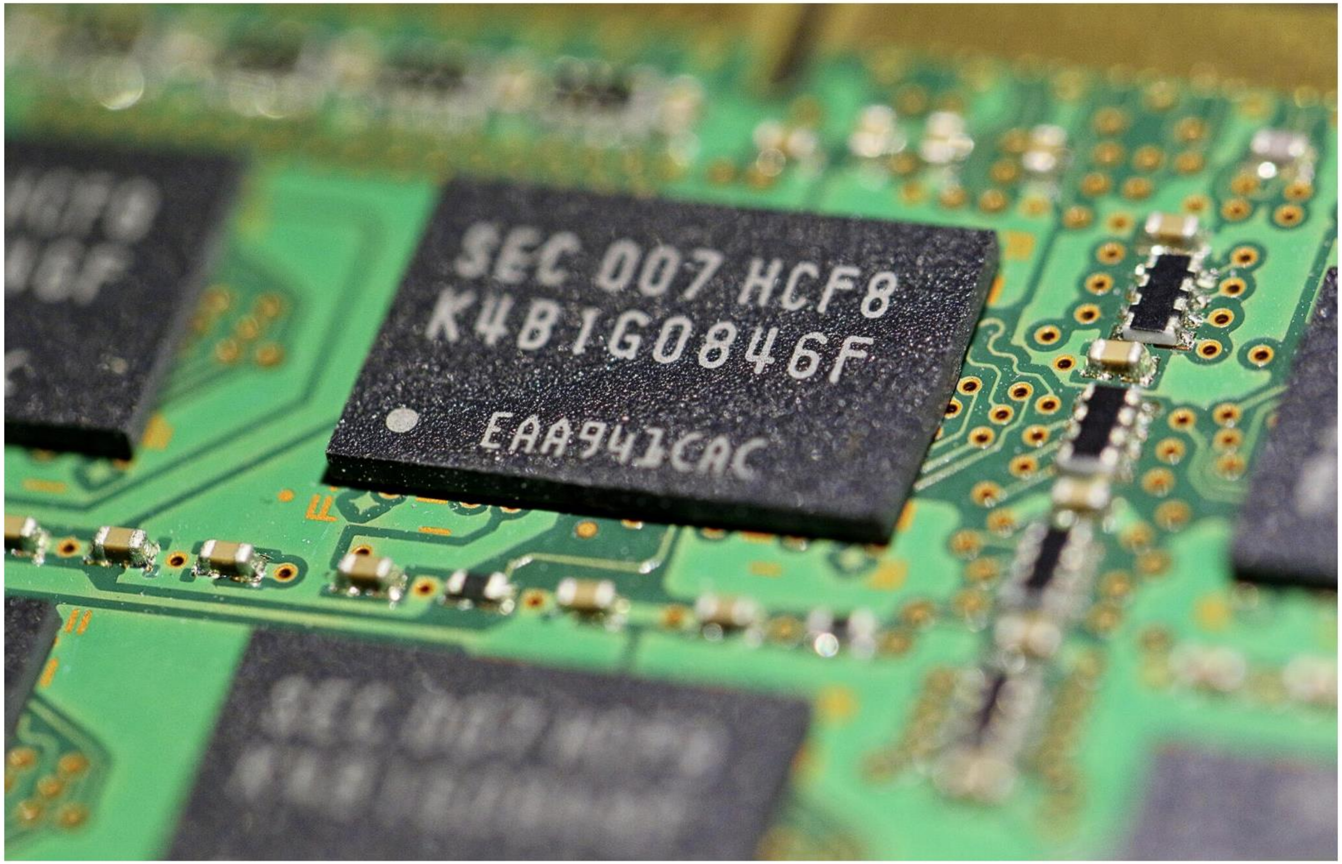
- Power generator
  (Mechanical to electric power)
- RF sensor
- Crash sensor



Study physics of semiconductors, devices and manufacturing methods.

1. Basic of Semiconductor

Why should we study semiconductor ?



How South Korea's semiconductor industry may become the global leader by 2030

January 10, 2023 **Korea market**, **South Korea**

South Korea's semiconductor industry made up about 19.3% of the global market, propelled by its memory market.

1. Basic of Semiconductor

Why should we study semiconductor ?

The semiconductor industry and its classification system

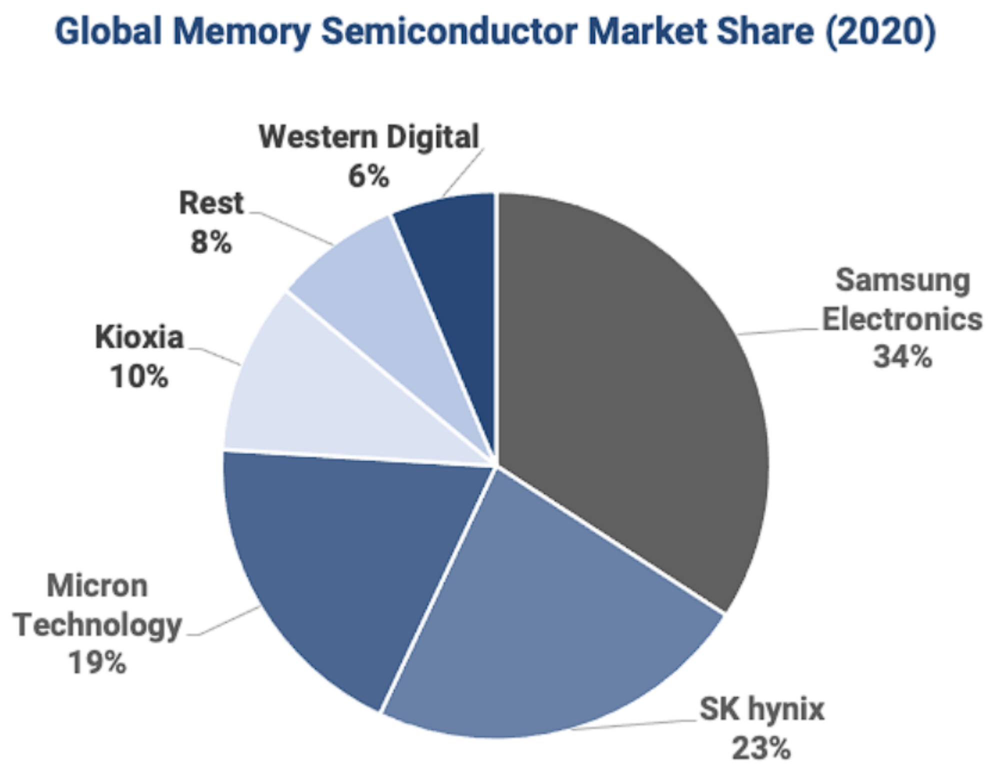
The semiconductor industry **can be classified** into four major groups: IDM, fabless, foundry, and OSAT. IDM (short for Integrated Device Manufacturer) companies **are responsible for the entire process of semiconductors**, from the planning to manufacturing and sales. Leading companies are Korean chaebols Samsung Group's **Samsung Electronics** (삼성 전자) and SK Group's **SK Hynix** (SK 하이닉스).

Whereas fabless companies like **Silicon Works** only design the semiconductors, the foundry companies like **DB HiTek (DB하이텍)** only manufacture them. OSAT (Outsourced Semiconductor Assembly and Test) companies like **HANA Micron** and **NEPES provide packaging and testing services**.

Classification	Characteristics	Major companies in South Korea	Major companies not in Korea
IDM	Companies that perform all production processes, including design, manufacturing, test, and packaging	Samsung Electronics SK hynix	Intel (USA)
Fabless	Companies that only design and develop without semiconductor manufacturing facilities	Silicon Works	Qualcomm (USA) Nvidia (USA) MediaTek (Taiwan)
Foundry	Companies that manufacture circuits on consignment, designed by fabless	DB HiTek	TSMC (Taiwan) GlobalFoundries (USA)
OSAT	Companies that assemble and test the finished wafers	HANA Micron NEPES	Amkor (USA) ASE (Taiwan)

1. Basic of Semiconductor

Why should we study semiconductor ?



daxueconsulting

Source: Bloomberg (2022), modified and re-designed by daxue consulting, Chip-reliant economy with Korean chaebols Samsung Electronics and SK hynix of South Korea's semiconductor industry

1. Basic of Semiconductor

So… What we are going to do?

Materials

What kind of materials are required?

Property

What kind of properties ?

Fabrication (Integration)

Let's made electronic device

Analysis

Electrical characteristics of the device

2. Characterization of Semiconductor

What is electrical characteristics of the device ?

Current–Voltage characteristic

A **current–voltage characteristic** or **I–V curve** (current–voltage curve) is a relationship, typically represented as a chart or graph, between the electric current through a circuit, device, or material, and the corresponding voltage, or potential difference, across it.

In electronics, the relationship between the direct current (DC) through an electronic device and the DC voltage across its terminals is called a current–voltage characteristic of the device

2. Characterization of Semiconductor

What is electrical characteristics of the device ?

The simplest I–V curve is that of a resistor, which according to **Ohm's law** exhibits a linear relationship between the applied voltage and the resulting **electric current**; the current is proportional to **the voltage**. the I–V curve is a straight line through the origin with positive slope. The reciprocal of the slope is equal to the **resistance**.

Resistance: *R*

From Ohm's law

$$R = V / I$$

the current *I* flowing through a bar of homogeneous material with uniform cross section when a voltage *V* is applied across it, we can find its resistance *R*

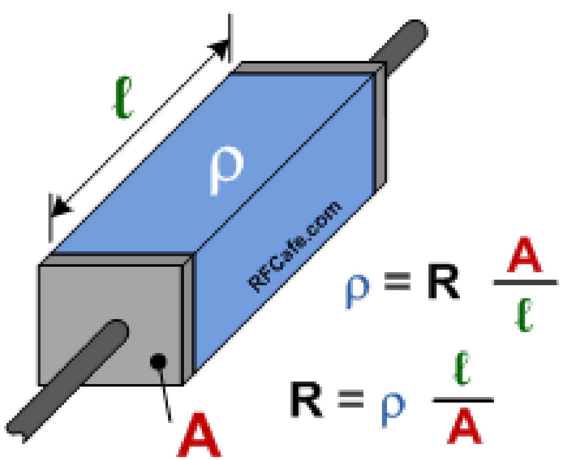
2. Characterization of Semiconductor

What is electrical characteristics of the device ?

Resistivity: ρ

$$\rho = R\frac{A}{L}$$

is related to the resistance of the bar by a geometric ratio where L and A are the length and cross-sectional area of the sample



Resistance: R

Resistivity: ρ

2. Characterization of Semiconductor

Types of I–V curves

The current (I) - voltage (V) relationship of electrical components can often provide insight into how electronic devices are used.
More specifically, many non-linear devices such as diodes and transistors are used in *operating regions* in which they behave like ideal components—such as current sources, voltage regulators, and resistors.

An understanding of I-V curves often provides insight into knowing how the device operates and helps us know how to operate a device in a way that enables the required functionality.

2. Characterization of Semiconductor

How to obtain I-V Curves

Method 1: Voltage Sweeps

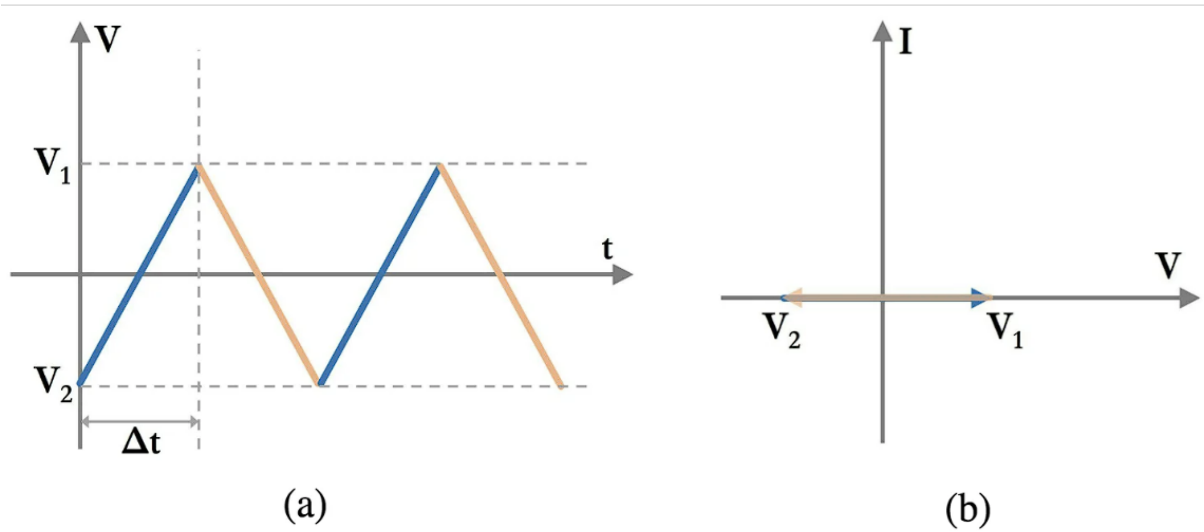
The current-voltage (*I*-*V*) relationship for a device is a current measured for a given voltage

For devices that do not supply power, I-V curves are obtained by using linear voltage sweeps.

Voltage sweeps involve the linear variation of the voltage, to obtain the corresponding measured output current.

(a): A linear sweep of voltage (V) with respect to time (t);

(b): the corresponding voltage sweep in the current (I) - voltage (V) curve



2. Characterization of Semiconductor

What kinds of facilities are we need?

Semiconductor parameter analyzer

- The semiconductor parameter analyzer is an all-in-one unit, that consists of a **power supplies**, **voltage meters**, **current meters**, **switching matrices** and **LCR meters** to test semiconductors.

- Conduct both current-voltage and capacitance measurements with just a semiconductor parameter analyzer.

3. Semiconductor parameter analyzer

Semiconductor parameter analyzer

Keithley 4200A-SCS Parameter Analyzer

Accelerate research, reliability and failure analysis studies of semiconductor devices, materials and process development with the 4200A-SCS. The highest performance parameter analyzer, it delivers synchronizing current-voltage (I-V), capacitance-voltage (C-V) and ultra-fast pulsed I-V measurements.

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3. Semiconductor parameter analyzer

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VS

Multimeter

3. Semiconductor parameter analyzer

Multimeter

A **<u>digital multimeter</u>** is a test tool used to measure two or more electrical values—principally voltage (volts), current (amps) and resistance (ohms)

Not for voltage sweep (I-V Curves)

3. Semiconductor parameter analyzer

Semiconductor parameter analyzer

Keithley 4200A-SCS Parameter Analyzer

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The Keithley Instruments Model 4200A-SCS Setup and Maintenance is a customizable and fullyintegrated parameter analyzer that provides synchronized insight into current-voltage (I-V), capacitance-voltage (C-V), and ultra-fast pulsed I-V characterization.

Old system consists of individual measurement instrument

Source meter / LCR meter / pulse generator / oscilloscope

3. Semiconductor parameter analyzer

Source measure unit (SMU)

Keithley 2400

LCR meter: capacitance

KEYSIGHT E4980A precision LCR meter

Pulse generator

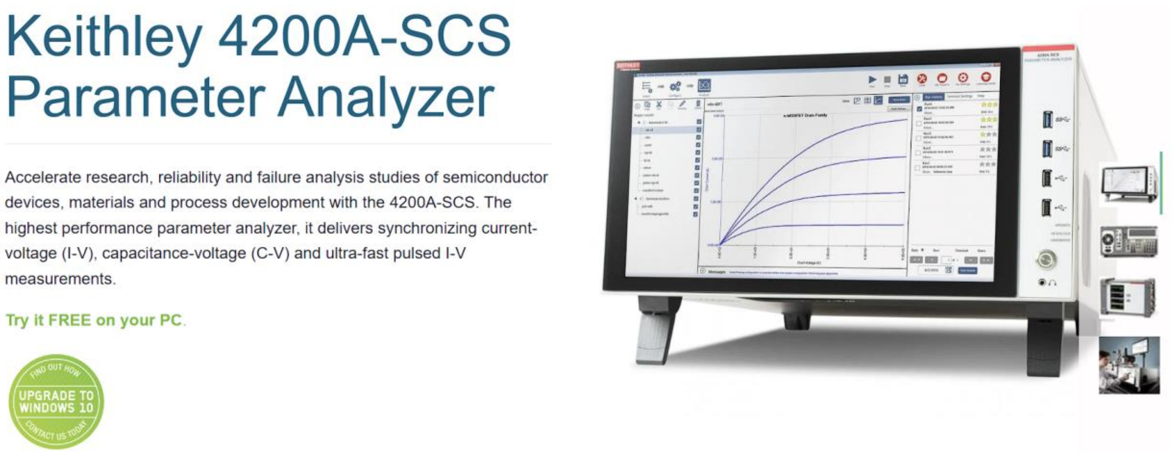
81134A Pulse Pattern Generator
Dual-Channel

Oscilloscope

MDO3000 Mixed Domain Oscilloscope

3. Semiconductor parameter analyzer

Semiconductor parameter analyzer



4200A-SCS system overview:

- An overall block diagram and summary of the system

- Basic configurations and capabilities of the source-measure units (SMUs), preamplifiers, pulse generator and measure units, and capacitance-voltage units (CVUs) that source and measure the electrical signals that are connected to your devices under test (DUTs)

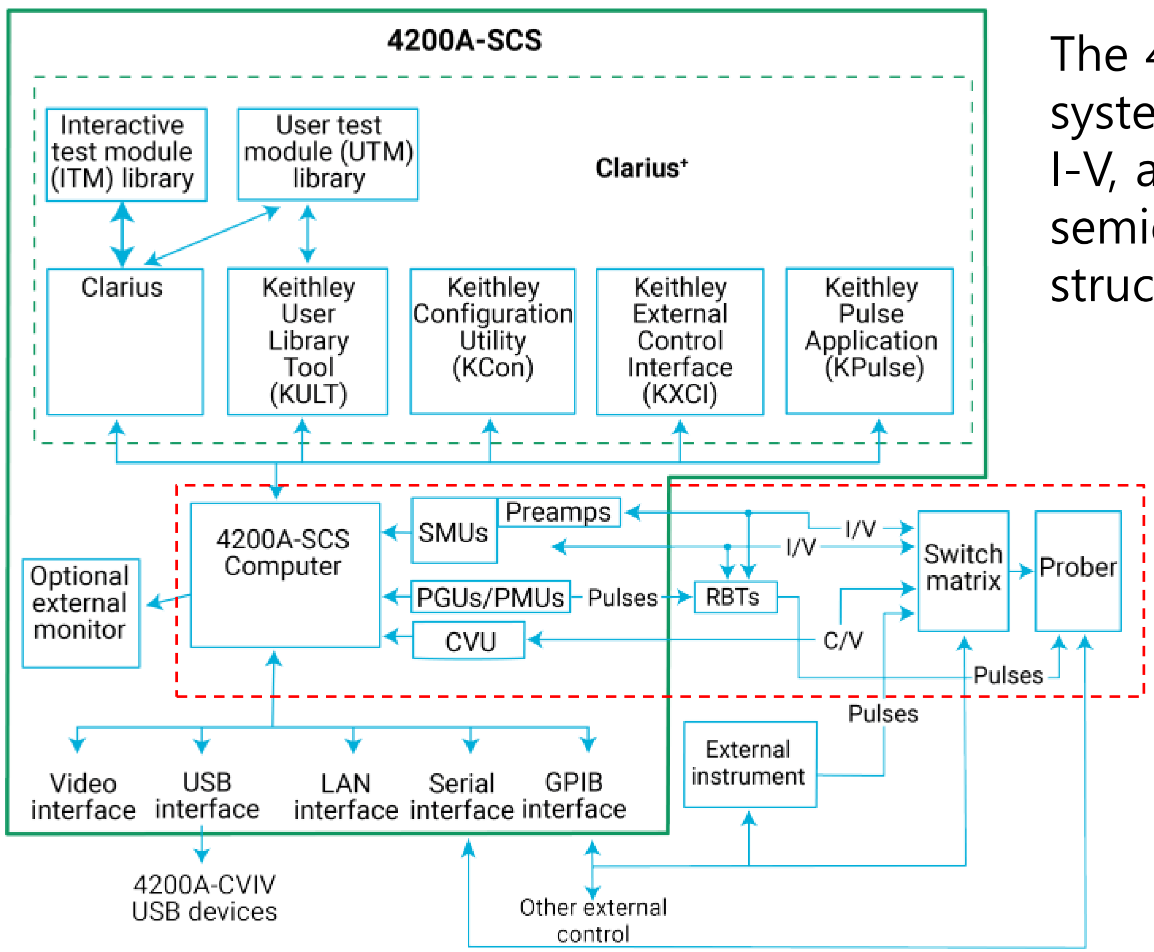
3. Semiconductor parameter analyzer

Semiconductor parameter analyzer

3. Semiconductor parameter analyzer

Semiconductor parameter analyzer

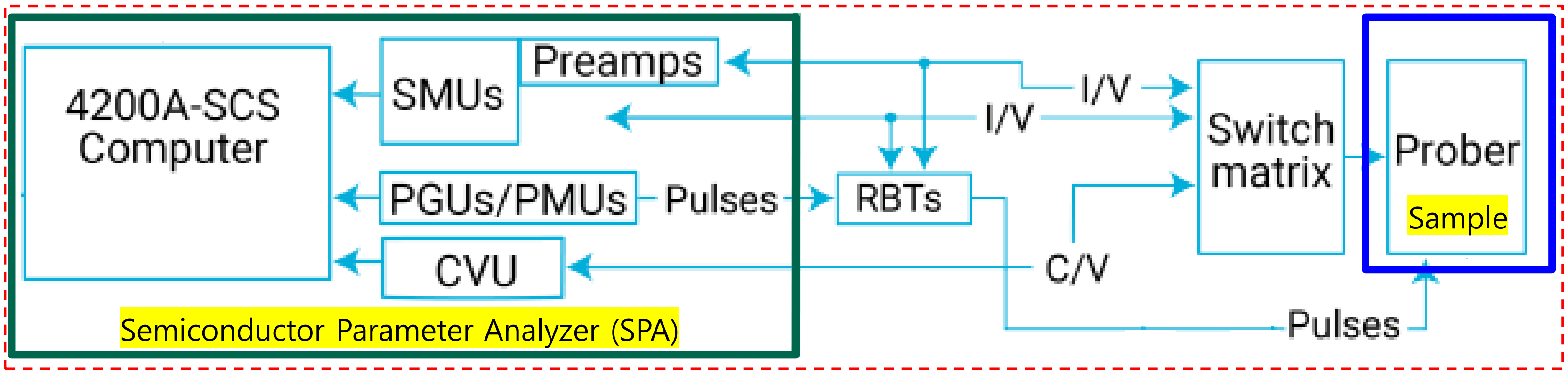
Figure 1: 4200A-SCS summary



The 4200A-SCS is an automated system that provides I-V, pulsed I-V, and C-V characterization of semiconductor devices and test structures

3. Semiconductor parameter analyzer

Measurement Configuration



- Source-measure unit (SMU)
- Ground unit (GNDU)
- Preamplifier
- Pulse source-measure hardware (PMU+RPM)
- Capacitance-Voltage Unit (CVU)

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