

Introduction to Microelectronics

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Key concepts, building blocks, and practical considerations

1. What Is Microelectronics?

Aspect	Description
Definition	The study and application of electronic circuits and devices that are fabricated on semiconductor substrates at micrometer (μm) to nanometer (nm) scales.
Goal	To integrate a large number of transistors and other components into a tiny area, achieving high functionality, speed, and low power consumption.
Typical Devices	MOSFETs, BJTs, diodes, capacitors, resistors, inductors, MEMS structures, photonic components.
Typical Platforms	Integrated circuits (ICs), system-on-chip (SoC), micro-electromechanical systems (MEMS), flexible electronics.

2. Historical Milestones

Year	Event	Impact
1947	Invention of the point-contact transistor (Bell Labs)	First solid-state amplification device.
1959	Invention of the MOSFET (Mohamed Atalla & Dawon Kahng)	Basis for modern digital ICs.
1960s	Development of planar process (Jean Hoerni)	Enabled reliable mass production of ICs.
1971	Intel 4004 – first commercial microprocessor	Demonstrated complex logic on a single chip.
1980s–1990s	CMOS scaling (Moore’s Law)	Exponential growth in transistor count.
2000s	Introduction of FinFETs, SOI, and high-κ/metal gate	Continued scaling beyond 45 nm.

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2020s	3nm and sub-10nm nodes, EUV lithography, heterogeneous integration	Pushes limits of physics, opens new materials.

3. Fundamental Device Physics

3.1 Semiconductor Basics

- **Band structure** – conduction band, valence band, bandgap (E_g).
- **Doping** – n-type (donors) and p-type (acceptors) creates free carriers.
- **Carrier transport** – drift (electric field) and diffusion (concentration gradient).

3.2 MOSFET (Metal-Oxide-Semiconductor Field-Effect Transistor)

Parameter	Symbol	Typical Meaning
Gate oxide thickness	(t_{ox})	Controls capacitance and leakage.
Threshold voltage	(V_{TH})	Gate voltage at which channel forms.
Transconductance	(g_m)	Change in drain current per gate-voltage change.
Subthreshold slope	(S)	How sharply the device turns off (mV/dec).

Operating regions

1. **Cutoff** – ($V_{GS} < V_{TH}$) ? off.
2. **Triode (linear)** – ($V_{GS} > V_{TH}$) and ($V_{DS} < V_{GS} - V_{TH}$).
3. **Saturation** – ($V_{GS} > V_{TH}$) and ($V_{DS} \geq V_{GS} - V_{TH}$).

3.3 Other Devices

- **BJTs** – current-controlled, useful for analog gain.
 - **Diodes** – PN junction, Schottky, Zener – rectification, clamping.
 - **MEMS resonators** – mechanical vibration for filters/sensors.
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