SNS COLLEGE OF TECHNOLOGY

An Autonomous Institution Coimbatore-35

Department of Artificial Intelligence and Data Science

23EET103 Electric Circuits and Electron Devices

I B.TECH-CSE-IOT/ II SEMESTER

UNIT IV : ELECTRONIC DEVICES AND APPLICATIONS

Topic : - Working principle and characteristics of MOSFET

Let’s Recall!!

- **Semiconductor basics** – n-type and p-type materials and charge carriers (electrons and holes).
- **PN junction diode** – depletion region, forward bias and reverse bias operation.
- **FET fundamentals** – Basic idea of voltage-controlled devices and channel conduction.

Topics for discussion

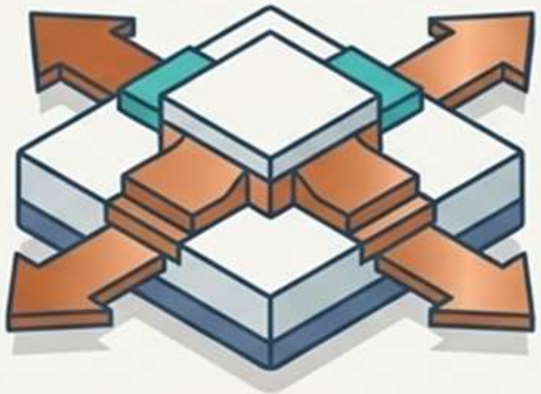
- Introduction to MOSFET (Metal Oxide Semiconductor Field Effect Transistor)
- Construction and Structure of MOSFET
- Types of MOSFET – Enhancement Mode and Depletion Mode
- N-Channel and P-Channel MOSFET
- Working Principle of MOSFET
- Operating Regions (Cut-off, Linear/Ohmic, Saturation)
- Drain Characteristics of MOSFET
- Transfer Characteristics of MOSFET
- Advantages of MOSFET (High input impedance, fast switching)
- Applications of MOSFET (Amplifiers, Switching circuits, Power electronics)

Why to Study MOSFET? *DT-Empathize*

The Legacy Bottleneck

Legacy transistors (BJTs and JFETs) face critical limitations in modern applications:

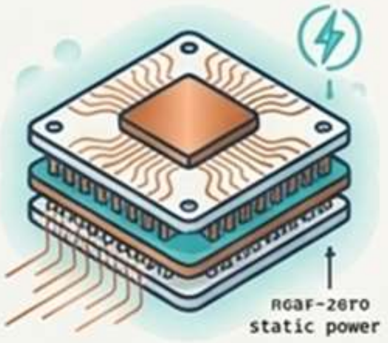
- **High Power Consumption**: Unsuitable for dense integrated circuits.
- **Gate Leakage**: Current loss during high-frequency operation.
- **Limited Scalability**: A barrier to extreme VLSI miniaturization.



The Modern Demand

Modern challenges require the exact opposite.

CMOS-based implantable medical devices and wearable biosensors demand ultra-low power to survive chronic implantation. The industry requires a solution with near-zero static power draw.



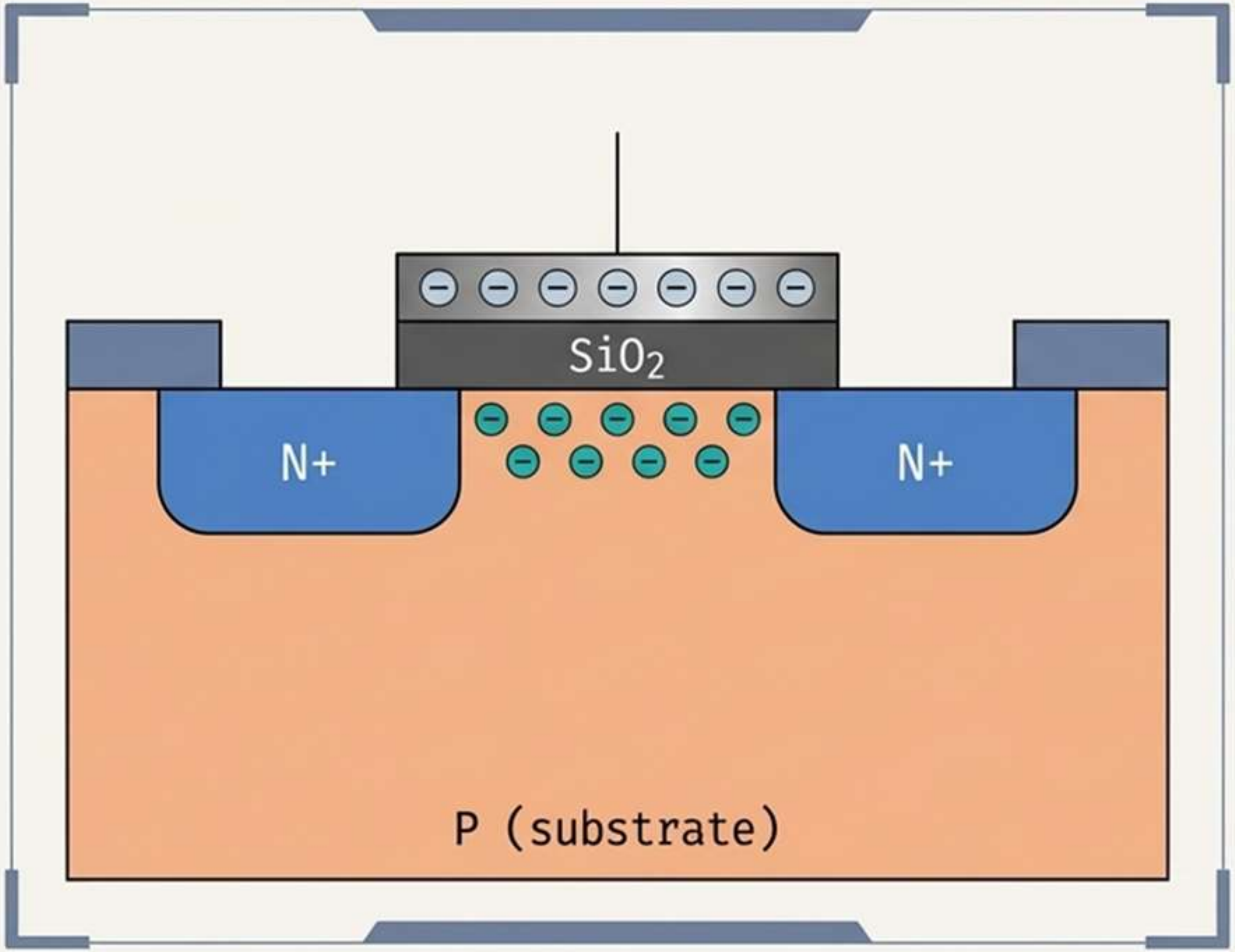
What is MOSFET *DT-DEFINE*

- MOSFET (Metal Oxide Semiconductor Field Effect Transistor) is an electronic device used for switching and amplifying signals in circuits.
- It is a voltage-controlled device, where the gate voltage controls the current flow between terminals.
- MOSFET is widely used in digital and analog electronic circuits.
- A MOSFET generally has four terminals.

Terminal	Symbol	Function
Gate	G	Controls channel formation via electric field through oxide
Source	S	Origin of majority carriers — defines reference potential
Drain	D	Destination of majority carriers — collects current
Body/Bulk	B	Semiconductor body — often connected to Source

A Layer-by-Layer Breakdown of MOSFET Anatomy

The physical construction of a MOSFET dictates its electrical capabilities:



Substrate (Body): The semiconductor bulk (P-type or N-type) providing mechanical support and electrical reference.

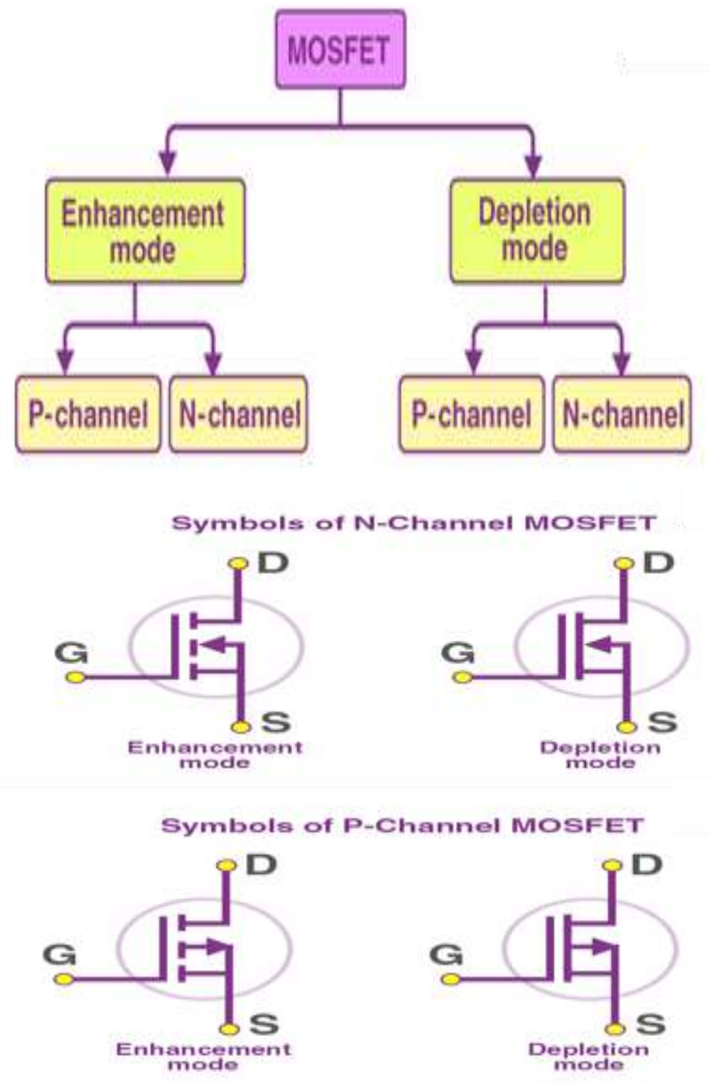
Source and Drain: Heavily doped regions (N+ or P+) that serve as the entry and exit points for charge carriers.

Gate Oxide: An incredibly thin silicon dioxide (SiO_2) insulator, typically just 10 to 100 nanometers thick.

Gate Terminal: A metal or polysilicon electrode sitting on top of the oxide, acting as one plate of a capacitor.

The Channel: The vital conducting path formed directly beneath the gate oxide between the Source and Drain.

Types of MOSFET



MOSFETs are categorized by their default physical state when zero gate voltage ($V_{GS} = 0$) is applied. Both modes are available in N-channel (electron flow) and P-channel (hole flow) variants.

Enhancement Mode (Normally OFF)

Highly preferred for switching and digital logic to save power.

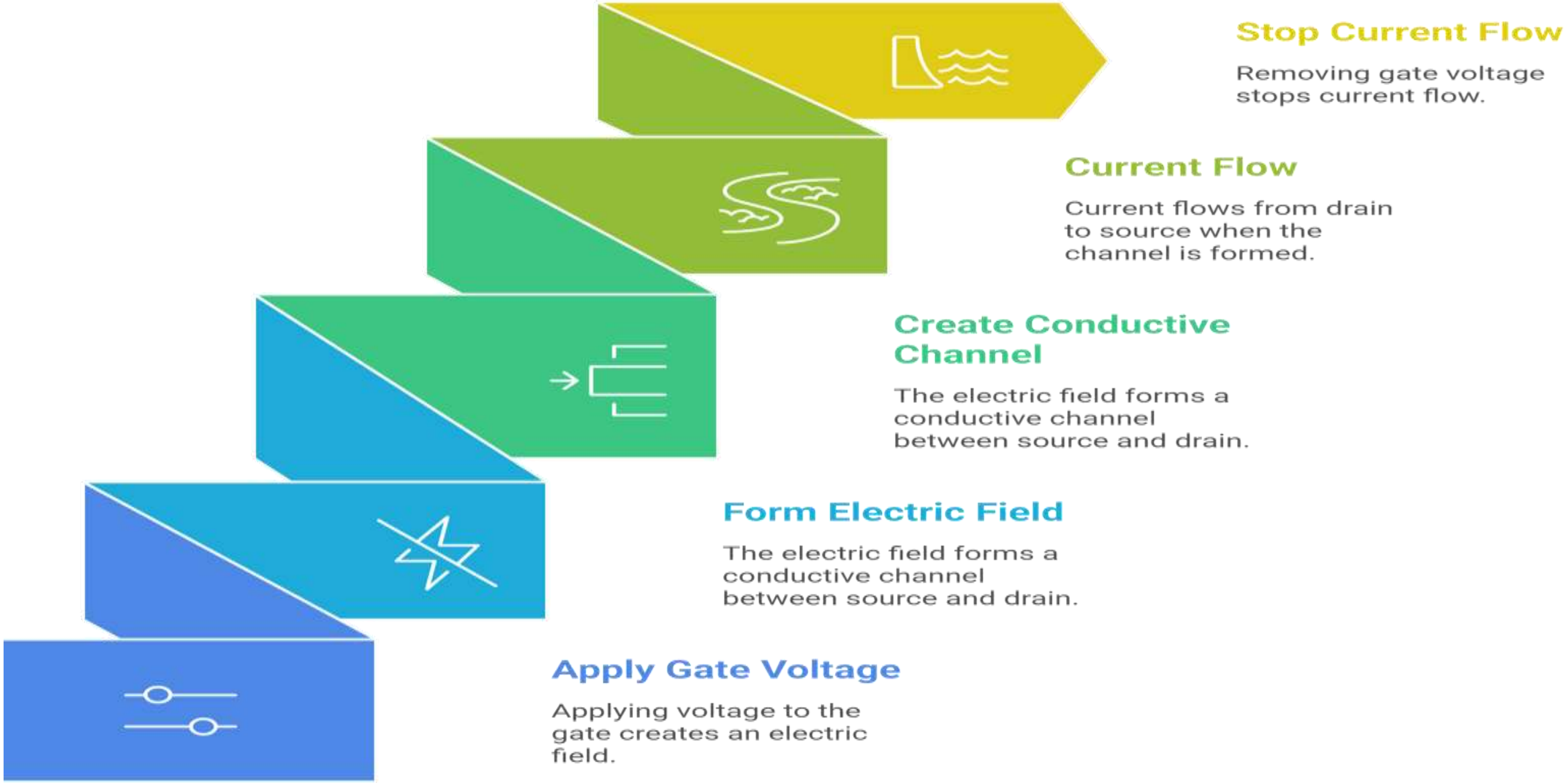
- No channel exists by default.
- The channel must be induced by applying a gate voltage exceeding a specific threshold.

Depletion Mode (Normally ON)

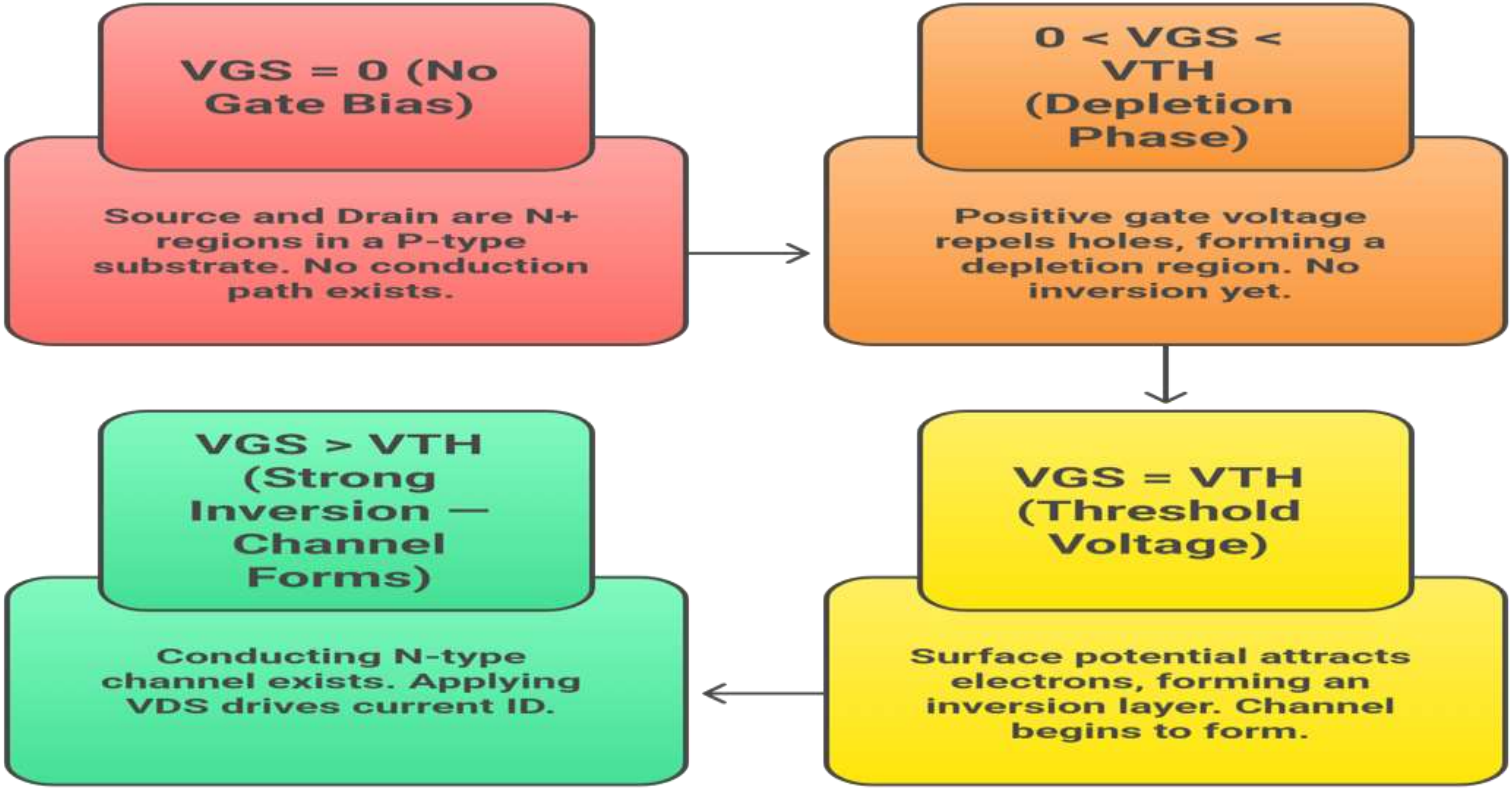
Gate voltage is applied to deplete the channel and reduce conductivity.

- A conductive channel is pre-doped during manufacturing.
- Current flows without any gate voltage.

Working of MOSFET



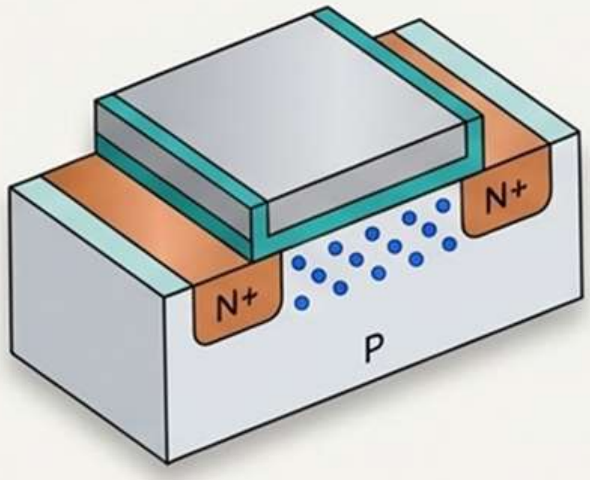
Working of Enhancement Mode MOSFET (N-Channel)



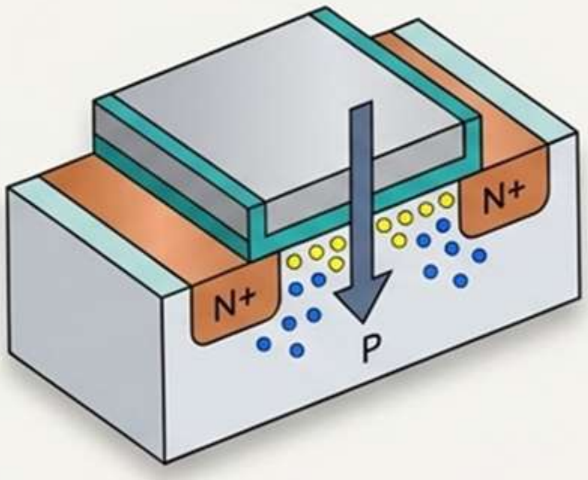
The Physics of Channel Inversion and The Field Effect

How an N-channel Enhancement MOSFET turns ON:

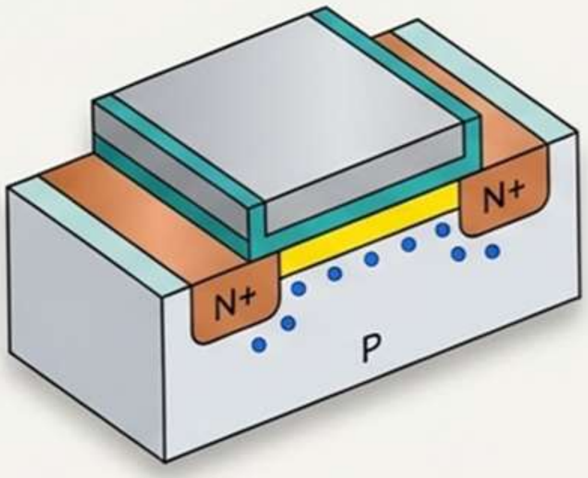
1. Zero Gate Bias ($V_{GS} = 0$)



2. Applying Positive Voltage ($+V_{GS}$)



3. Inversion Layer Formation ($V_{GS} > V_{TH}$)



1. Zero Gate Bias ($V_{GS} = 0$)

Holes dominate the P-type substrate interface. No conductive path exists between the N+ Source and Drain.

2. Applying Positive Voltage ($+V_{GS}$)

The metal gate acts as a capacitor plate. The electric field repels positive holes downward and attracts free electrons to the silicon surface.

3. Inversion Layer Formation ($V_{GS} > V_{TH}$)

Once the gate voltage exceeds the Threshold Voltage (V_{TH}), a continuous N-type conductive path is formed.

Regions of Operation

The behavior of the MOSFET changes drastically based on the relationship between **Gate-Source voltage** (V_{GS}) and **Drain-Source voltage** (V_{DS}).

Cut-off Region

Condition: $V_{GS} < V_{TH}$

Behavior: The device is OFF. No channel is formed, and Drain current (I_D) is zero.

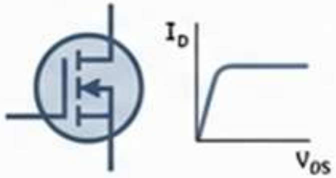
Ohmic / Linear Region

Condition: $V_{DS} < V_{GS} - V_{TH}$

Behavior: The channel is intact. The MOSFET acts as a voltage-controlled resistor. I_D rises linearly with V_{DS}.

Saturation / Active Region

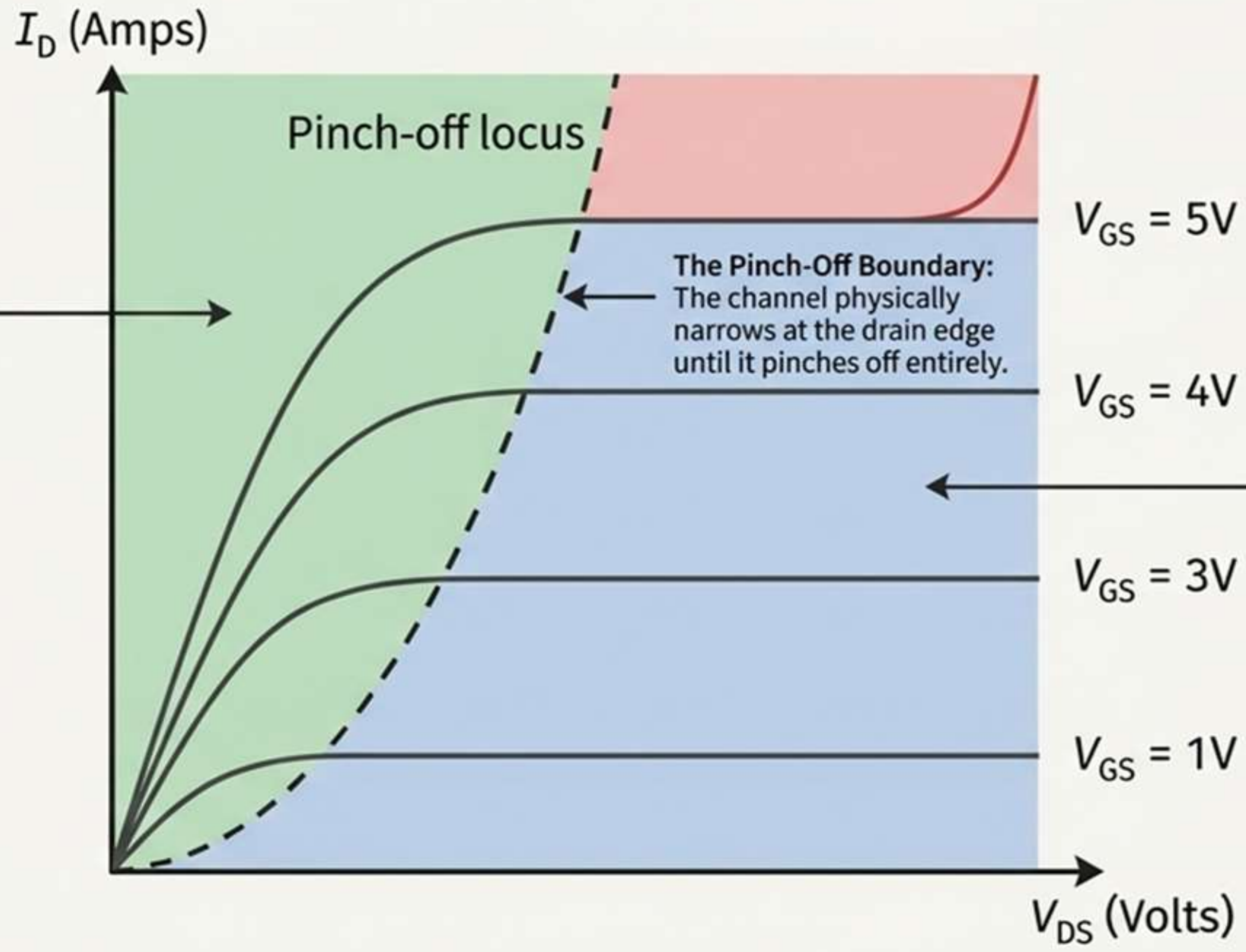
Condition: $V_{DS} \geq V_{GS} - V_{TH}$



Behavior: The channel "pinches off" near the drain. The Drain current (I_D) becomes relatively constant, independent of further increases in V_{DS}.

Output Characteristics:

The Output Characteristics curve visualizes how Drain Current (I_D) responds to changes in Drain-Source Voltage (V_{DS}).

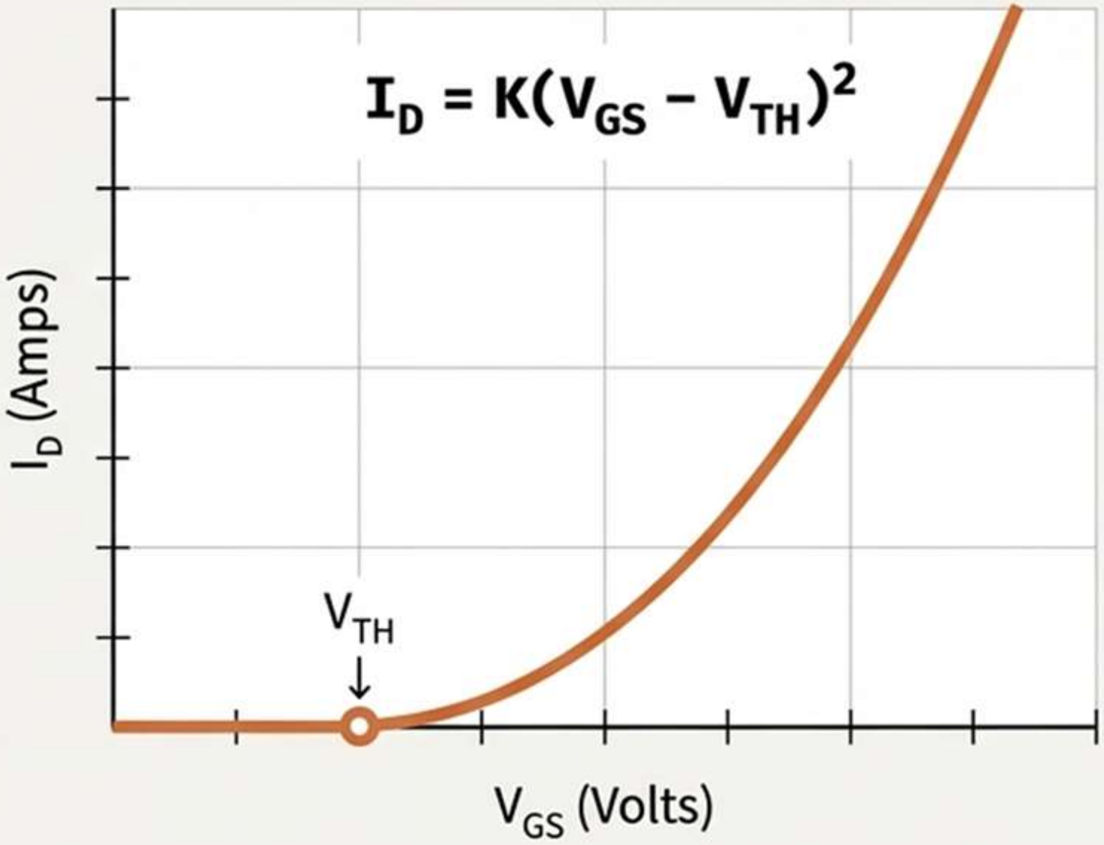


Voltage-Controlled Resistor: In the Ohmic region, higher V_{GS} means lower resistance.

Amplification Zone: In the Saturation region, the device acts as a constant current source.

Transfer Characteristics and Square-Law Behavior

The Transfer Characteristic defines the gain and biasing of the device by mapping input voltage to output current.



- **V_{TH} (Threshold Voltage):** The exact point on the X-axis where the device transitions from Cut-off to active conduction (typically 0.5V to 4V).
- **Transconductance (g_m):** The slope of this curve dictates the change in Drain current per change in Gate voltage—a critical metric for designing analog amplifiers.

MOSFET Technology

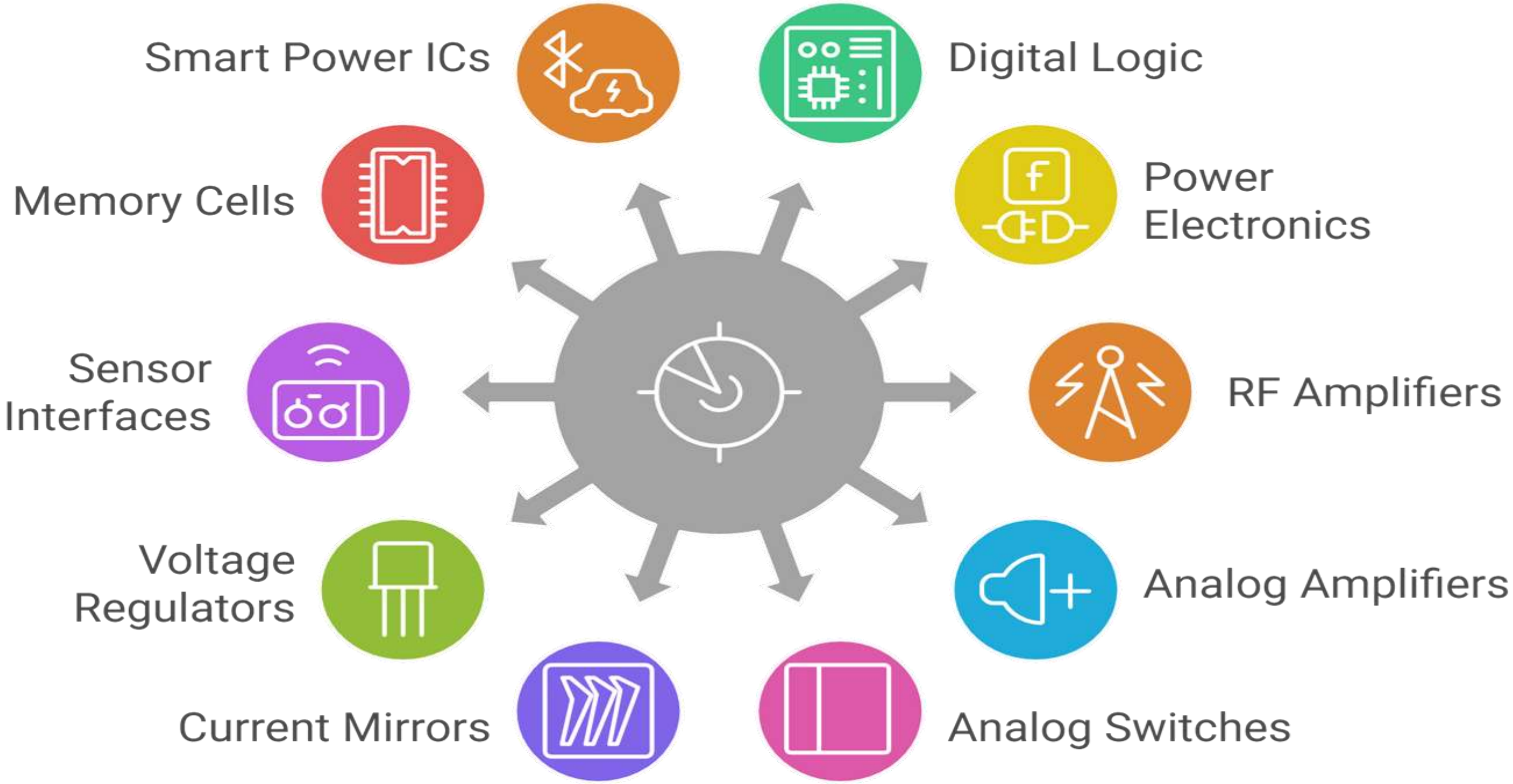
Pros

1. **High input impedance**
   No loading on preceding stages, ideal for high-impedance sources.
2. **Scalability**
   Smallest feature sizes (sub-2nm nodes) enable miniaturization.
3. **Low power**
   Ultra-low power in CMOS for battery-operated devices.
4. **Fast switching**
   Picosecond transitions in advanced nodes for high-speed applications.
5. **Safe paralleling**
   Positive temperature coefficient of RDS(on) ensures safe paralleling.

Cons

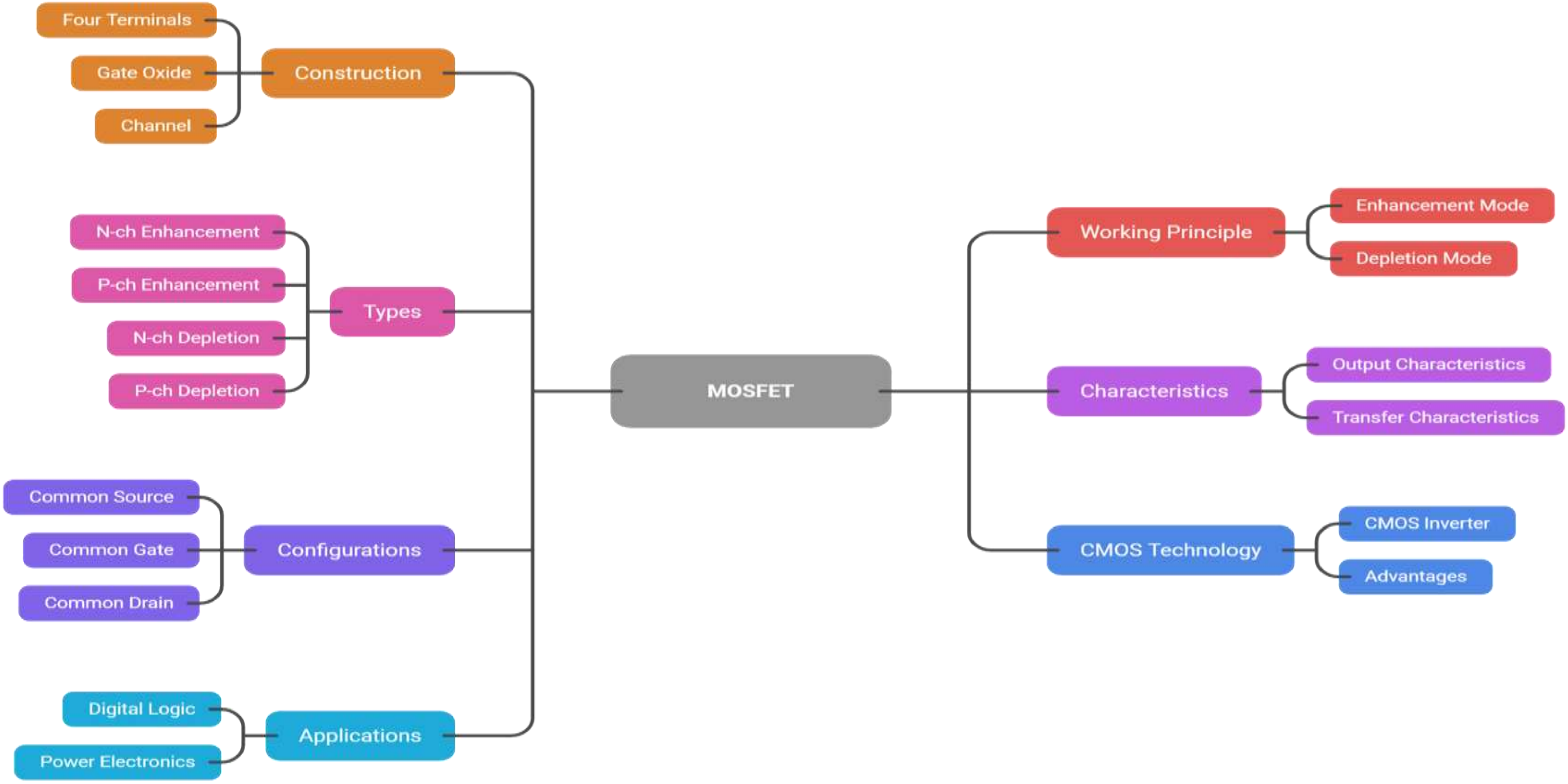
1. **Lower transconductance**
   Lower gain per stage compared to BJT.
2. **ESD susceptibility**
   Gate oxide susceptible to ESD damage, requiring protection.
3. **Short channel effects**
   Severe short channel effects below 10nm gate length.
4. **Gate leakage**
   Gate leakage increases in ultra-thin oxide devices.
5. **Subthreshold slope**
   Subthreshold slope limit restricts steep turn-off.

Applications of MOSFET *DT-IDEATE*



Summary

Let's Summarize



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Thank You