MOS Transistor (Structure)

BASIC SEMICONDUCTOR CONCEPT

- Silicon (Si)
  - Silicon forms basic starting material for a large class of IC.
  - Pure Silicon consists of a three-dimensional lattice (cubic cr
  - Group IV element, forms covalent bonds with four adjacent
  - Poor conductor.

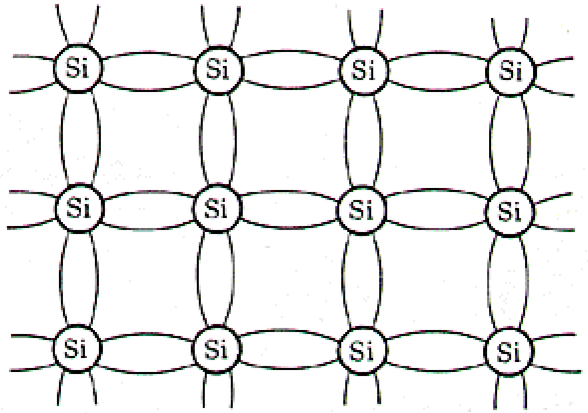


Figure: Silicon lattice

- Dopant
  - Small amount of impurities for raising conductivity.
- Two types of dopant
  - Group V dopant: Arsenic (As), and others
  - Thermal vibration of lattice at room temperature is enough to set the electron free to move.
  - Creates n-type semiconductor because of negative charge of electron.

BASIC SEMICONDUCTOR CONCEPT

- Group III dopant: Boron (B) and others
- Borrow electron from neighboring silicon atom, which in turn becomes short by one electrons.
- So the missing electron or hole can propagate.
- Creates p-type semiconductor because hole acts as a positive carrier.

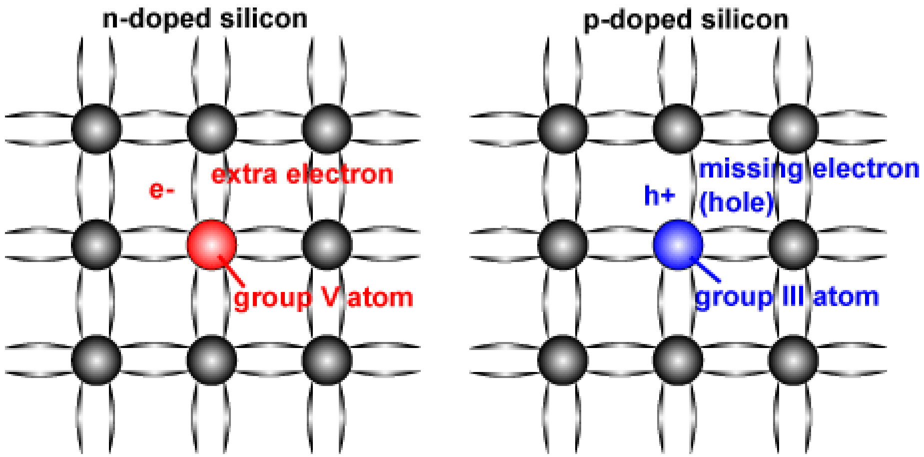


Figure: Silicon with dopants

BASIC SEMICONDUCTOR CONCEPT

- Diode
  - A junction between p-type and n-type semiconductor.
  - **Forward Bias:** voltage on p-type semiconductor (called anode) is raised above the n-type (called cathode). As a result, current flows.
  - **Reverse Bias:** anode voltage is less than or equal to the cathode voltage. **Almost zero current flows.**

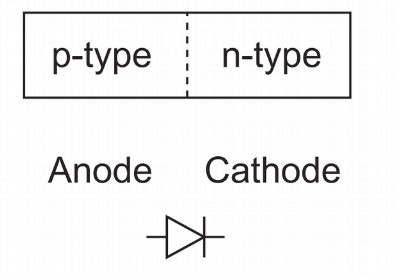
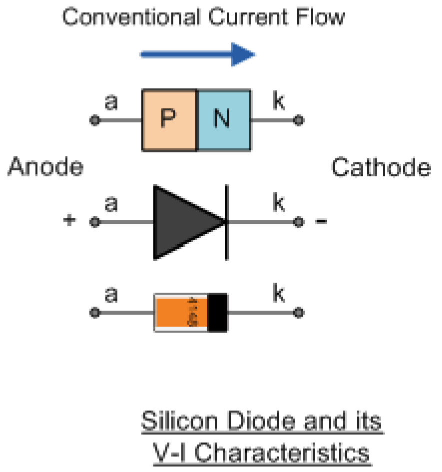


Figure: p-n junction structure and symbol

- Diode Characteristic Graph
  - Forward Bias region
  - Reverse Bias region
    - Reverse Breakdown voltage
    - Leakage Current
  - Threshold Voltage
  - Depletion Region



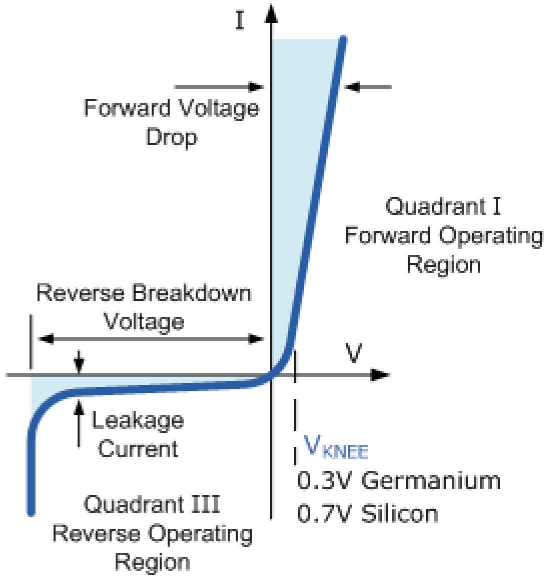
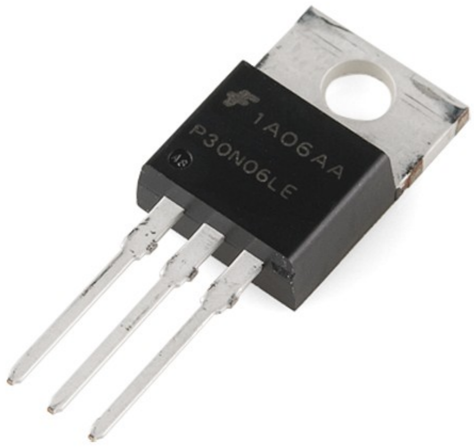


Figure: Diode V-I characteristic graph

MOS TRANSISTOR

MOSS



MOS

MOS TRANSISTOR

- MOS (Metal-Oxide-Semiconductor)
  - Superimposed several layers of conducting and insulating materials to form a sandwich-like structure.
  - Series of chemical processing steps involving oxidation of Silicon, diffusion of impurities, deposition and etching of Aluminum.
  - Process carried on a single crystal of silicon, which is available as thin flat circular wafers around 15-30 um.

- Transistor operation is based on electric field. So these devices are called MOSFET, or simply FET.
- Parts of MOSFET:
  - Stack of the conducting gate
  - Insulating layer of SiO_2
  - Silicon Wafer (also called Substrate, body or bulk)

MOSFET TYPES

- nMOS and pMOS
- nMOS
  - p-type body
  - Two regions of n-type semiconductor near gate: Source and Drain. (physically equivalent)
  - Source and Drain are heavily doped.
  - Body is typically grounded.
- pMOS
  - n-type body
  - Two regions of p-type semiconductor near gate: Source and Drain. (physically equivalent)
  - Source and Drain are heavily doped.
  - Body is typically held at high potential.

- So MOSFET is a 4-terminal device. Gate, Source, Drain and Body.

NMOS & PMOS

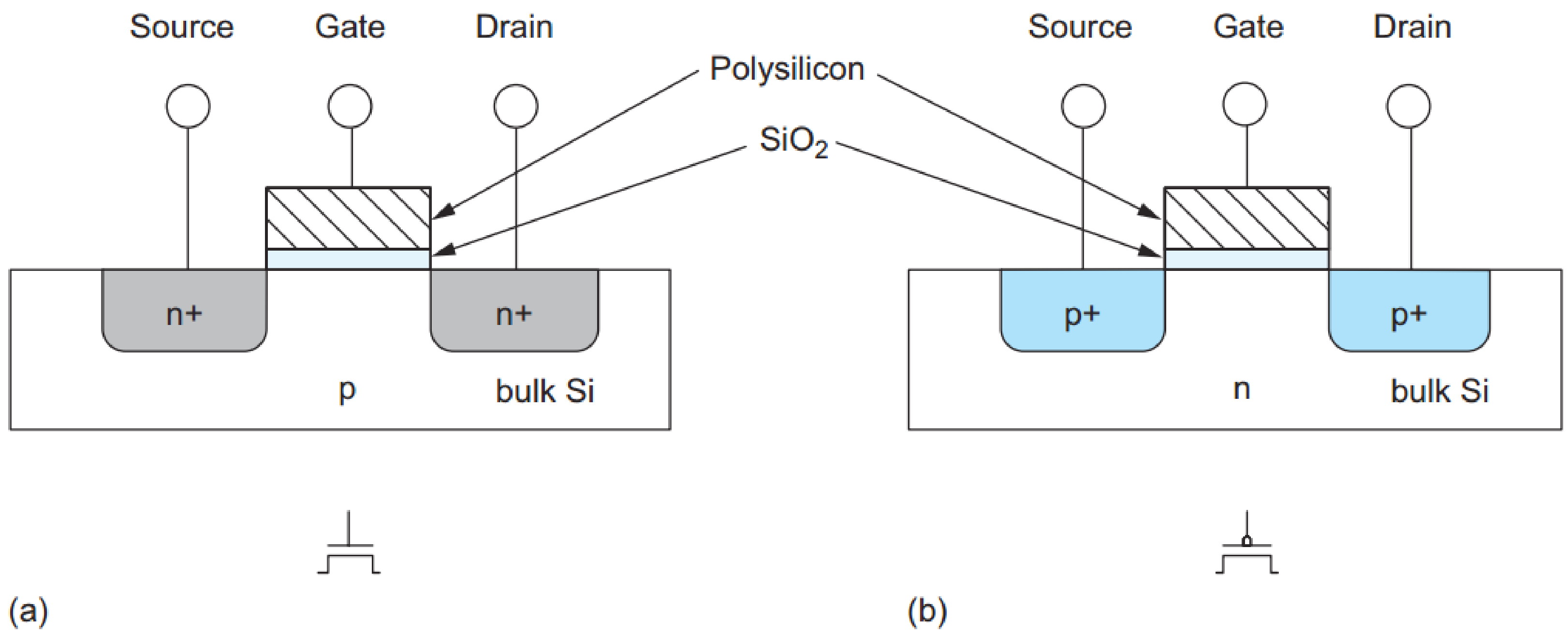


FIGURE 1.9 nMOS transistor (a) and pMOS transistor (b)

MOSFET SYMBOLS

- 4-terminal device
  - In figure (a) all terminals are shown
  - In figure (b) terminal B is not shown
  - Figure (c) is normally used in digital circuit. (switch symbol)

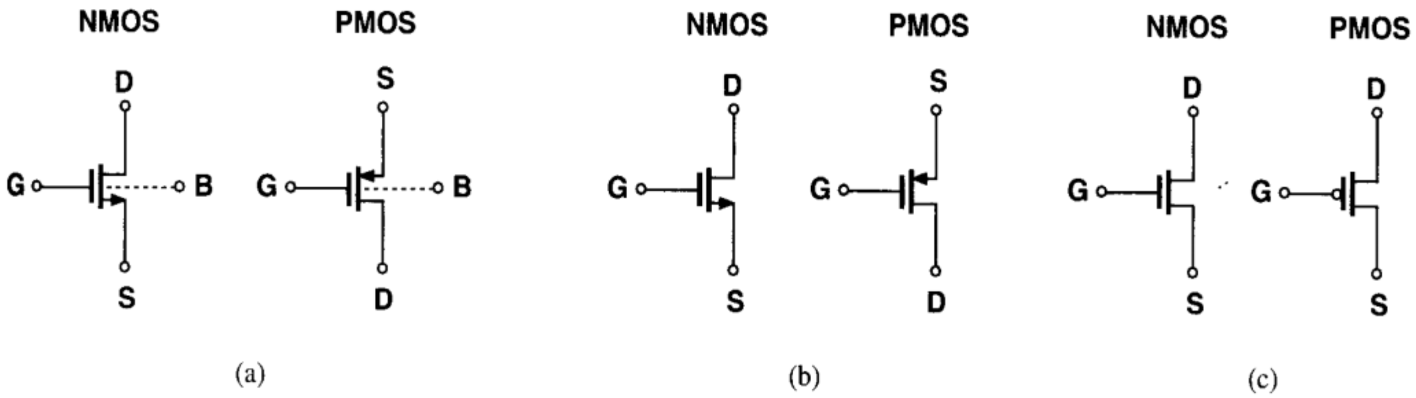
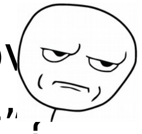


Figure 2.5 MOS symbols.

- In most circuits Bulk (B) terminal is tied to:
  - nMOS -> ground
  - pMOS -> V_{DD}
  - So, generally they are omitted from the signal. We will mostly use the symbol in (b).

MOSFET STRUCTURE

- Substrate
  - Substrate potential greatly influences the device characteristics.
  - In typical MOS operation, S/D junction diode must be reverse-biased.
  - We assume that, substrate of nMOS is connected to most negative supply of the system.
  - Actual connection is prov  through an ohmic p+ region.
    - What the heck is “ohmic”?

- Ohmic Contact:
  - An ohmic contact is a non-rectifying electrical junction; a junction between two conductors that has a linear current-voltage (I-V) relationship or curve as with the Ohm’s law.

MOSFET STRUCTURE

- Substrate Connection

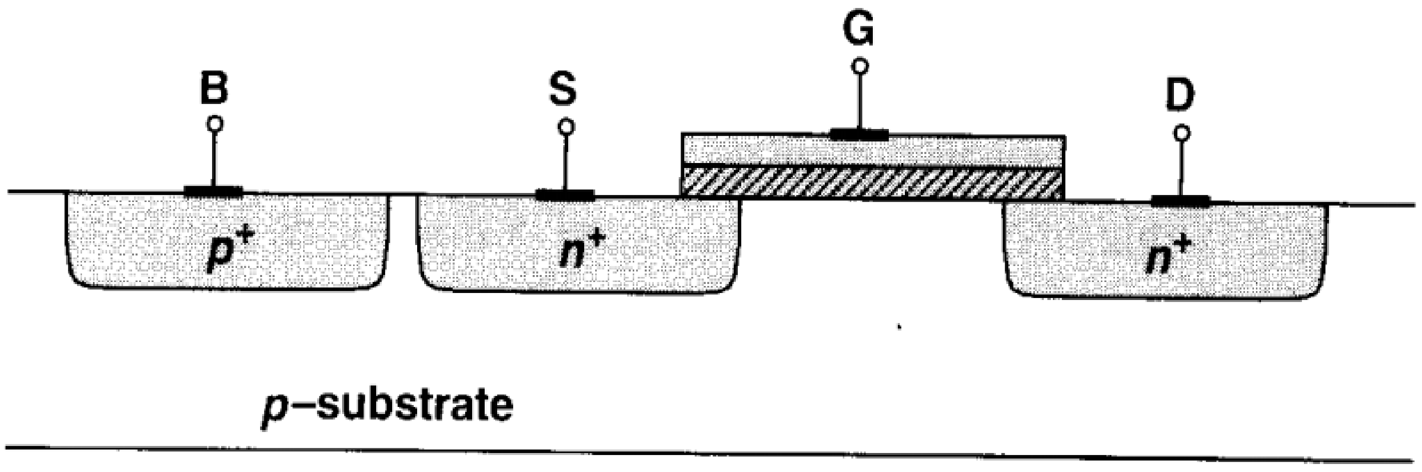


Figure 2.3 Substrate connection.

MOSFET STRUCTURE

- Gate:
  - Early it was build from metal (the stack was called metal-oxide-semiconductor).
  - Now gate is typically formed from polycrystalline (polysilicon).

  - Gate is a control input.
  - Affects the current flow between S and D.

- How does it affect?

EFFECTS OF GATE VOLTAGE

- For nMOS:
  - Body is generally grounded.
  - If gate is also grounded (g=0), p-n junction of S and D to body are reverse-biased.
  - So, no current flows, the MOSFET is OFF.
  - If gate voltage is raised, it creates an electric field that starts to attract free electrons to the underside of the Si-SiO_2 interface.
  - If the voltage is raised enough (gate voltage>threshold voltage), the electrons outnumber the holes, and the thin region under the gate called the “channel” is inverted to act as a n-type semiconductor.
  - Hence, a conducting path of electron carriers is formed from S to D, and current can flow. Now the MOSFET is ON.
- For pMOS: Just the opposite. (Think yourself!)

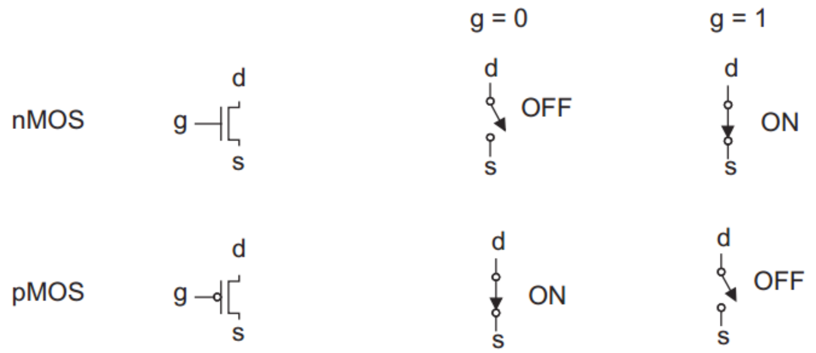


FIGURE 1.10 Transistor symbols and switch-level models

MOSFET STRUCTURE

- Length, L: dimension of the gate along the source-drain path (remember Feature Size?)
- Width, W: dimension perpendicular to the length

- Actual distance between source and drain is less than L. Why?
  - S/D junctions "side-diffuse" during the fabrication process.
  - $L_{eff} = L_{drawn} - 2L_D$
    - Here, L_{eff} is the effective length, L_{drawn} is the total length, and L_D is the amount of diffusion.
    - L_{eff} and the gate oxide thickness (t_{ox}) play an important role in the performance of MOS circuit.
    - From generation to generation, the principal thrust of MOS technology is to reduce both of these dimensions.

  - However, we will denote L_{eff} as L in throughout the course.

MOSFET STRUCTURE

$L_{eff} = L_{drawn} - 2L_D$

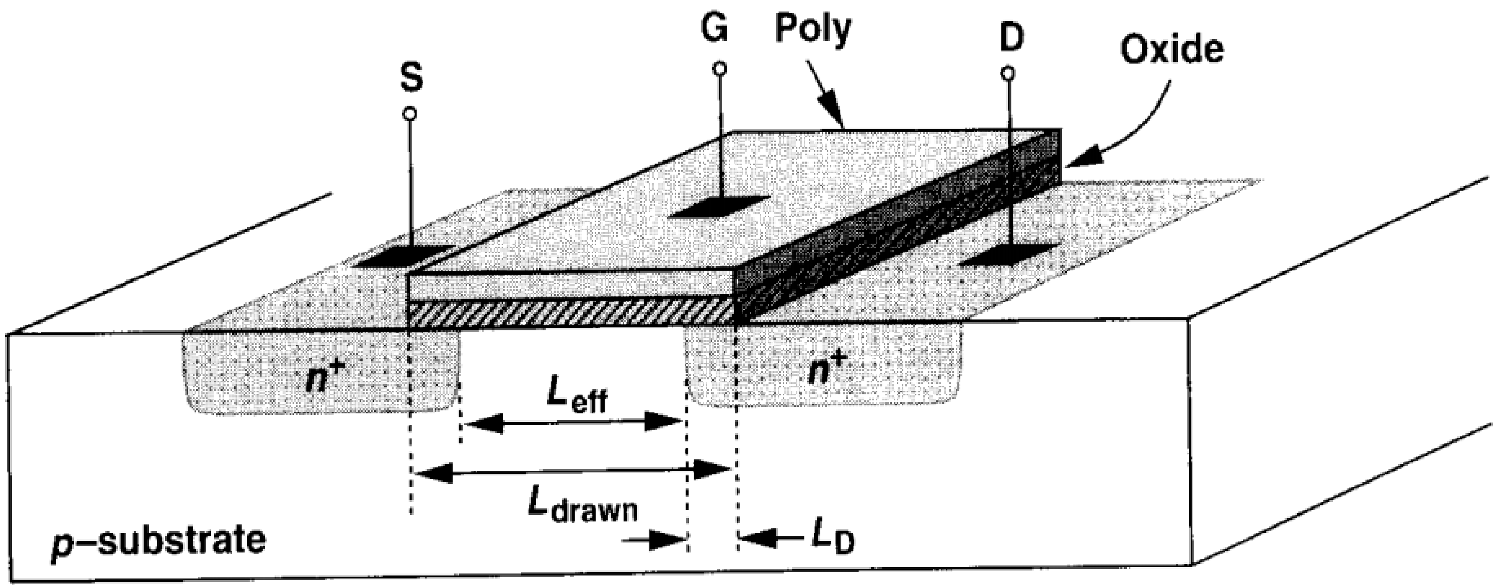


Figure 2.2 Structure of a MOS device.

REFERENCE

- Weste
  - 1.3
- Razavi
  - 2.1