Semiconductor Manufacturing Technology

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Chapter 3

Device Technologies

Objectives

After studying the material in this chapter, you will be able to:

1. Identify differences between analog and digital devices and passive and active components. Explain the effects of parasitic structures in passive components.
2. Describe the PN junction, why it is important, and explain reverse and forward biasing.
3. State the characteristics of bipolar technology and the bipolar junction transistor in terms of function, biasing, structure and applications.
4. Explain the basic characteristics of CMOS technology, including the field effect transistor, biasing and the CMOS inverter.
5. Explain the difference between enhancement and depletion mode MOSFETs.
6. Explain the effects of parasitic transistors and the implications for CMOS latchup.
7. Give examples of IC products and state some applications of each.

Circuit Types

- Analog Circuits
  - Radio transceivers, audio, automotive ignition
- Digital Circuits
  - Computer, calculator, “high” or “low”

Components on Printed Circuit Board

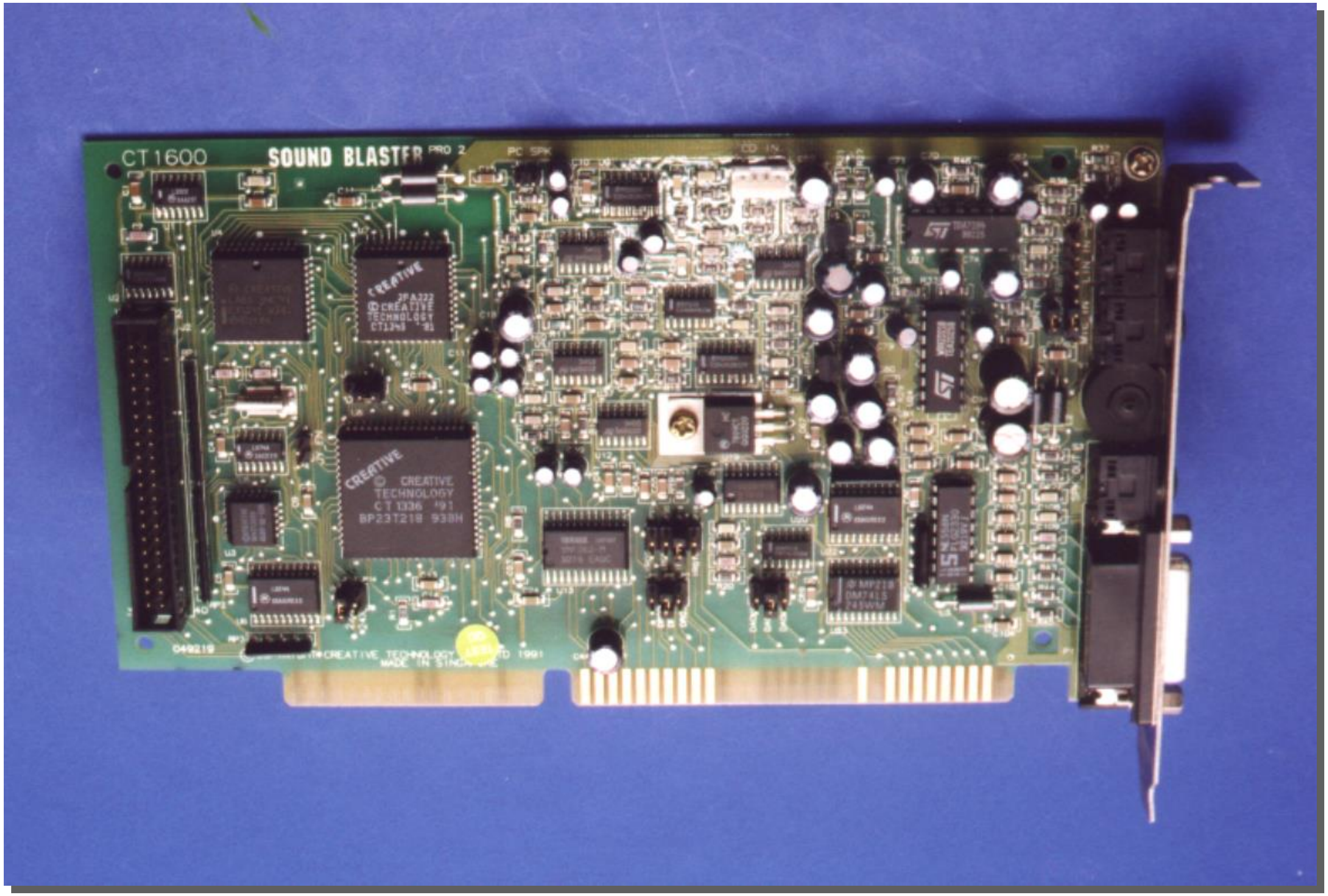


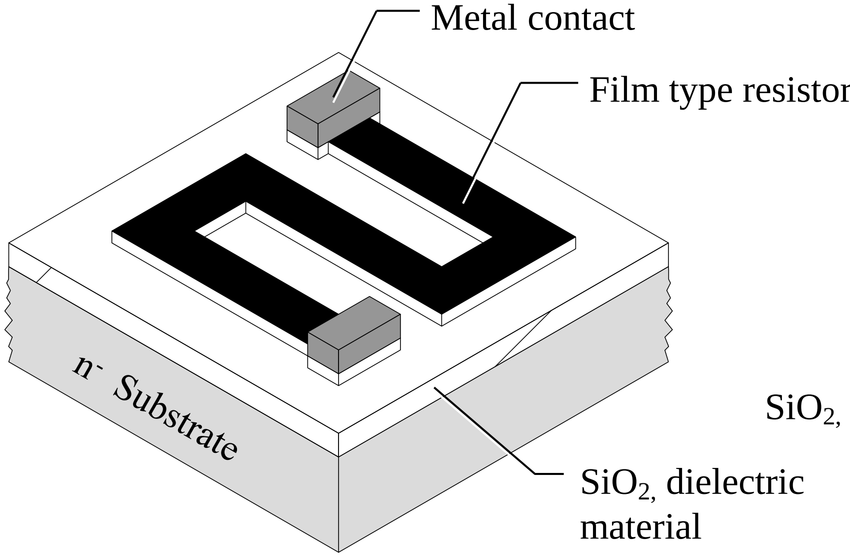
Photo 3.1

Passive Component Structures

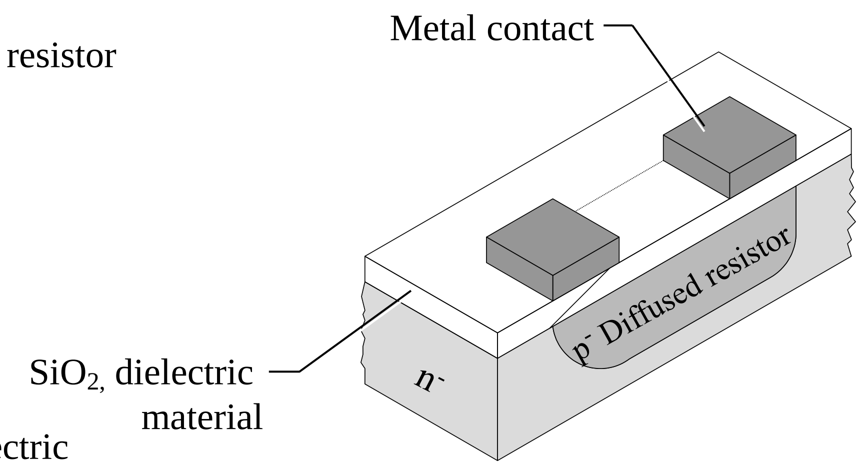
An active element is capable of generating energy while a passive element is not.

- IC Resistor Structures (R)
  - Parasitic Resistor Structures
- IC Capacitor Structures (C)
  - Parasitic Capacitance Structures
- IC Inductor Structures (L)

Examples of Resistor Structures in ICs



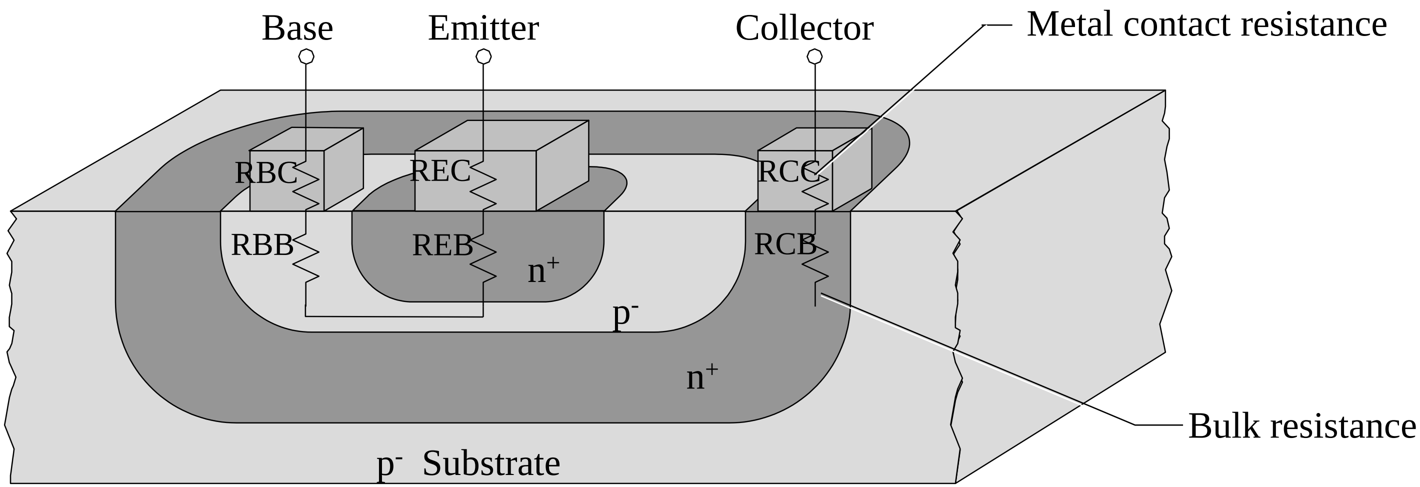
Metal film type



Diffusion dopant

Figure 3.1

Cross Section of Parasitic Resistances in a Transistor



- It reduces the operational performance of IC devices.
- Higher density comes higher resistance .

Figure 3.2

Examples of Capacitors Structures in ICs

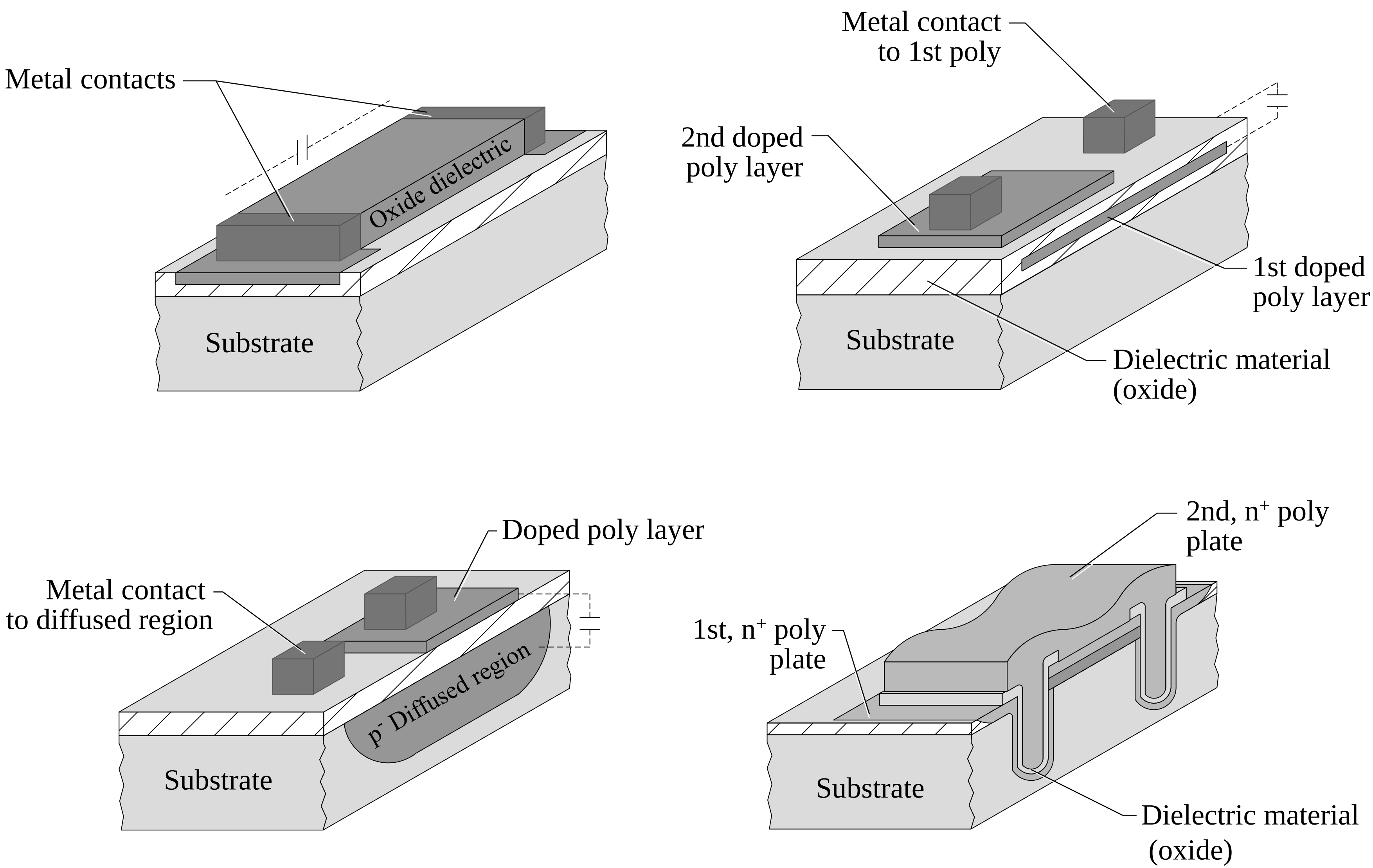
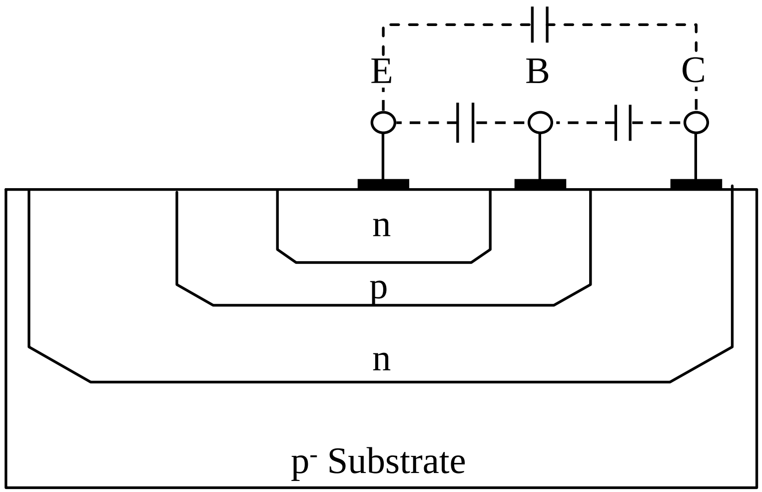
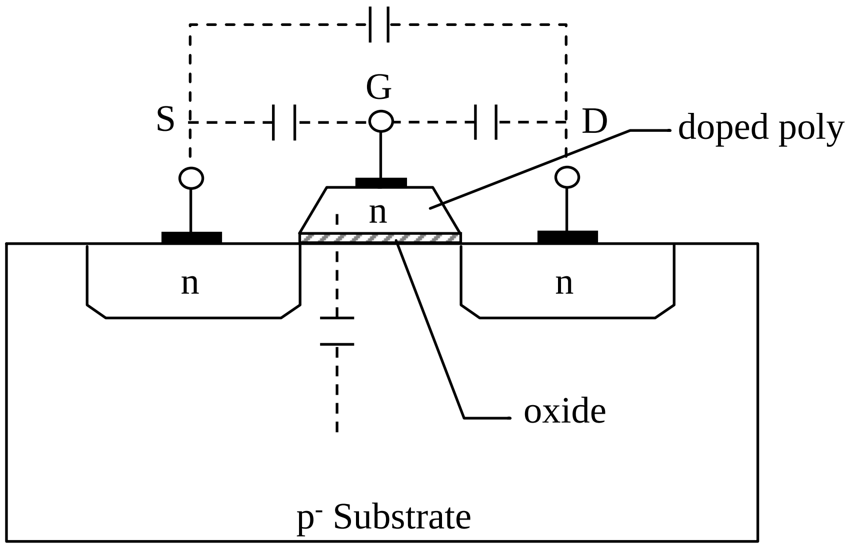


Figure 3.3

Parasitic Capacitance in Transistors



Bipolar junction transistor

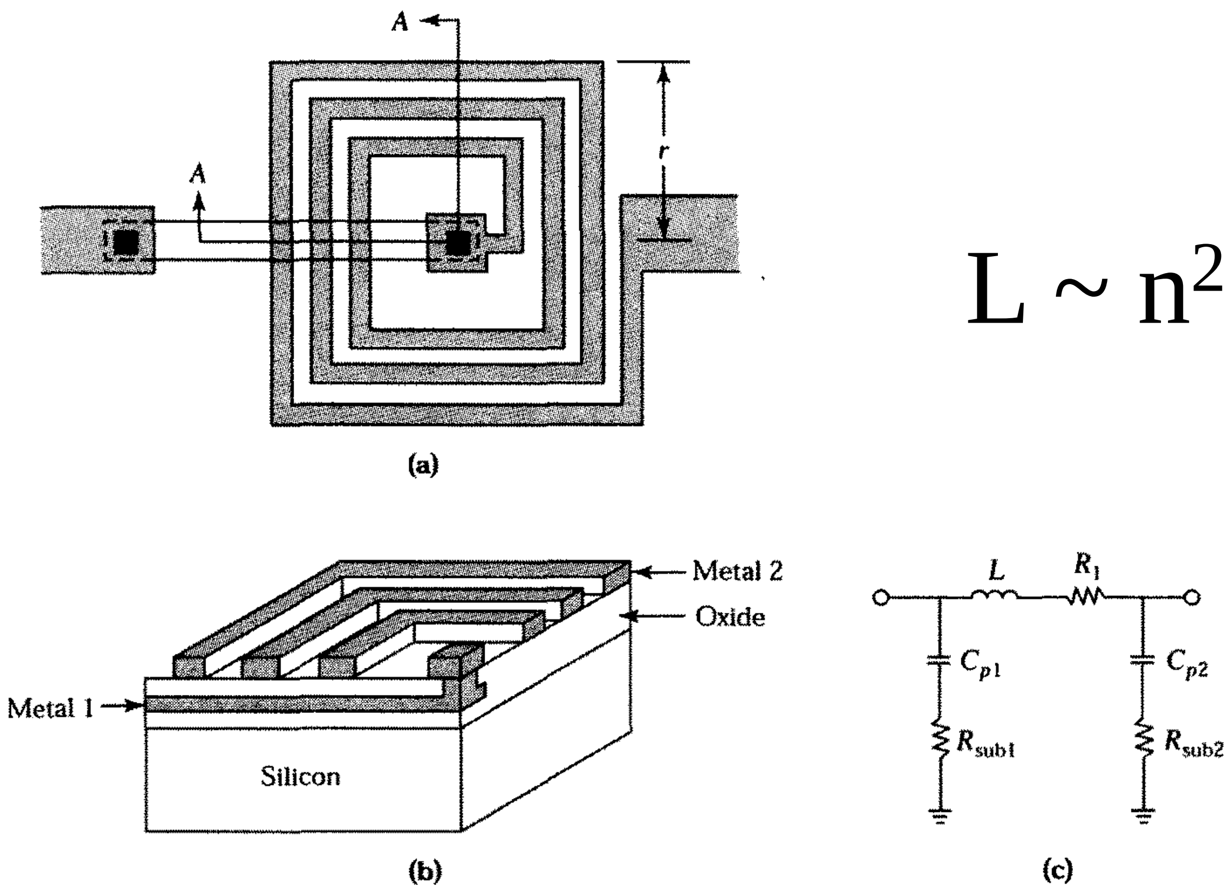


Field effect transistor

- Parasitic capacitance may create instability in circuits, even short-circuit paths for AC signals where they are not need.

Figure 3.4

Integrated-Circuit Inductor



$$L \sim n^2$$

Fig. 5 (*a*) Schematic view of a spiral inductor on a silicon substrate. (*b*) Perspective view along *A-A′*. (*c*) An equivalent circuit model for an integrated inductor.

Active Component Structures

- Used to control current direction and amplify small signal
- The pn Junction Diode
- The Bipolar Junction Transistor
- Schottky Diode
- Bipolar IC Technology
- CMOS IC Technology
- Enhancement and Depletion-Mode MOSFETs

Basic Symbol and Structure of the pn Junction Diode

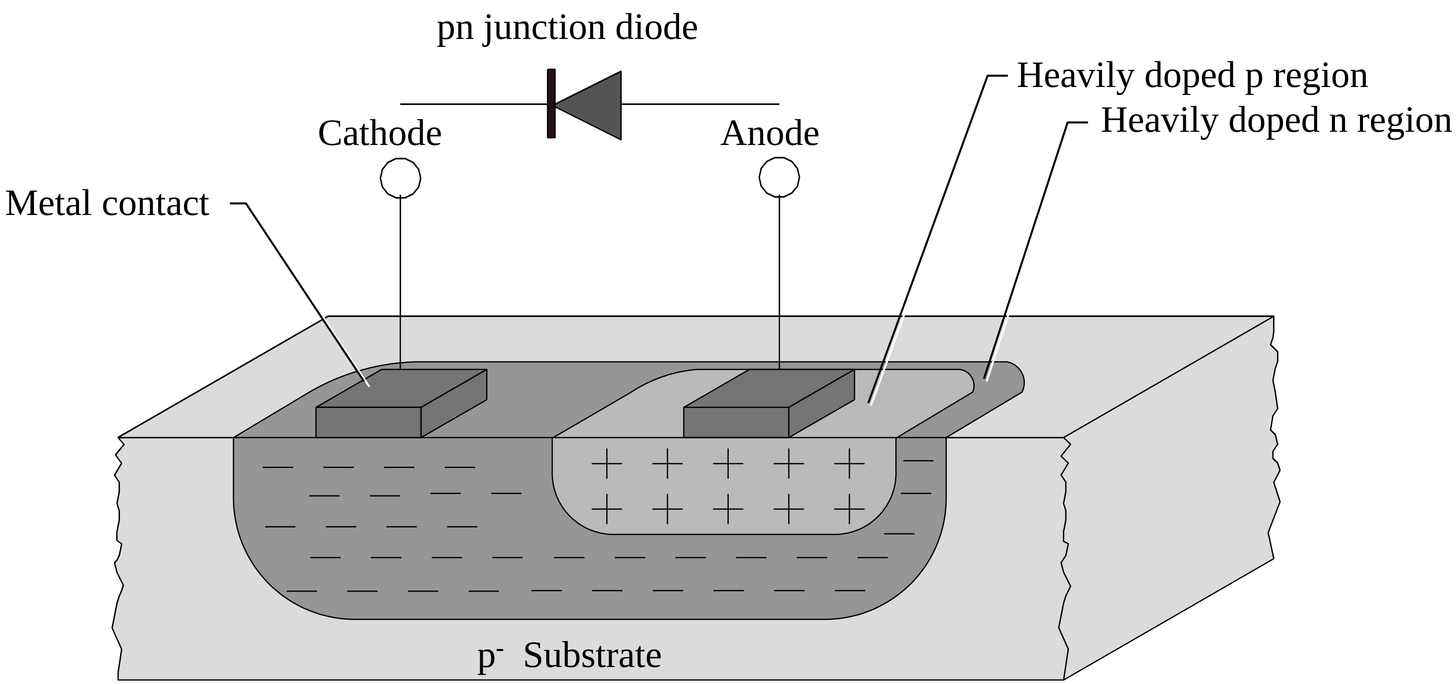


Figure 3.5

Open-Circuit Condition of a pn Junction Diode

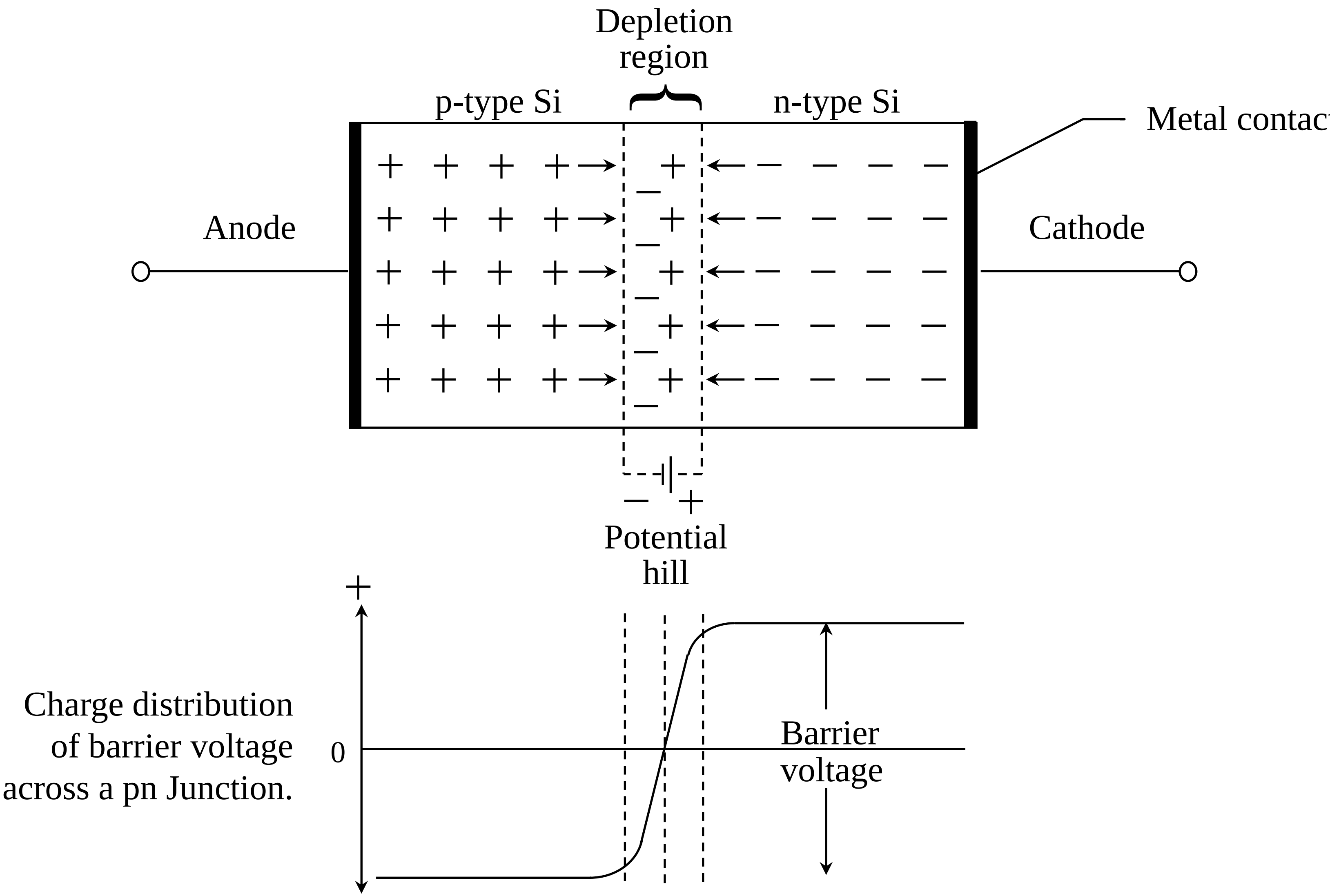


Figure 3.6

Reverse-Biased PN Junction Diode

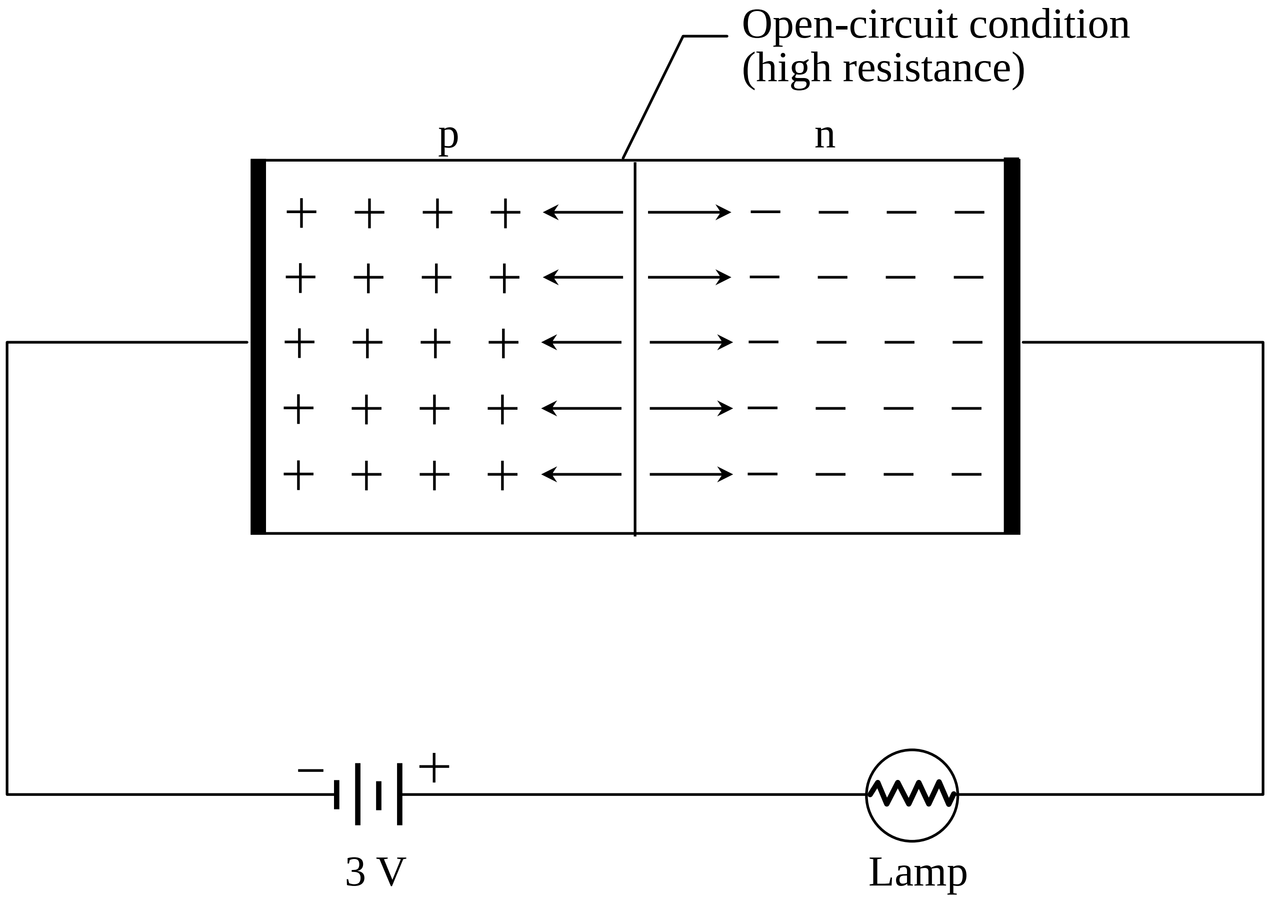


Figure 3.7

Forward-Biased PN Junction Diode

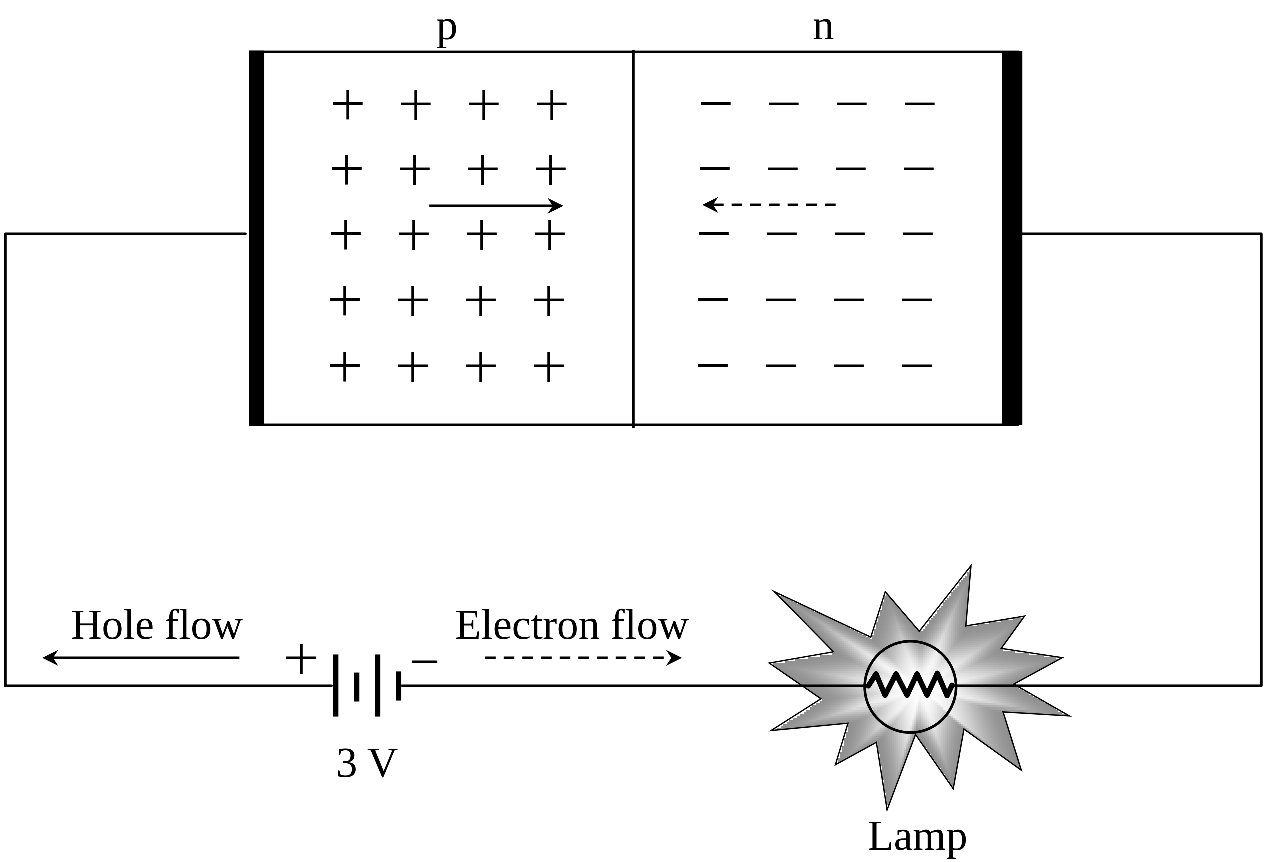


Figure 3.8

Forward and Reverse Electrical Characteristics of a Silicon Diode

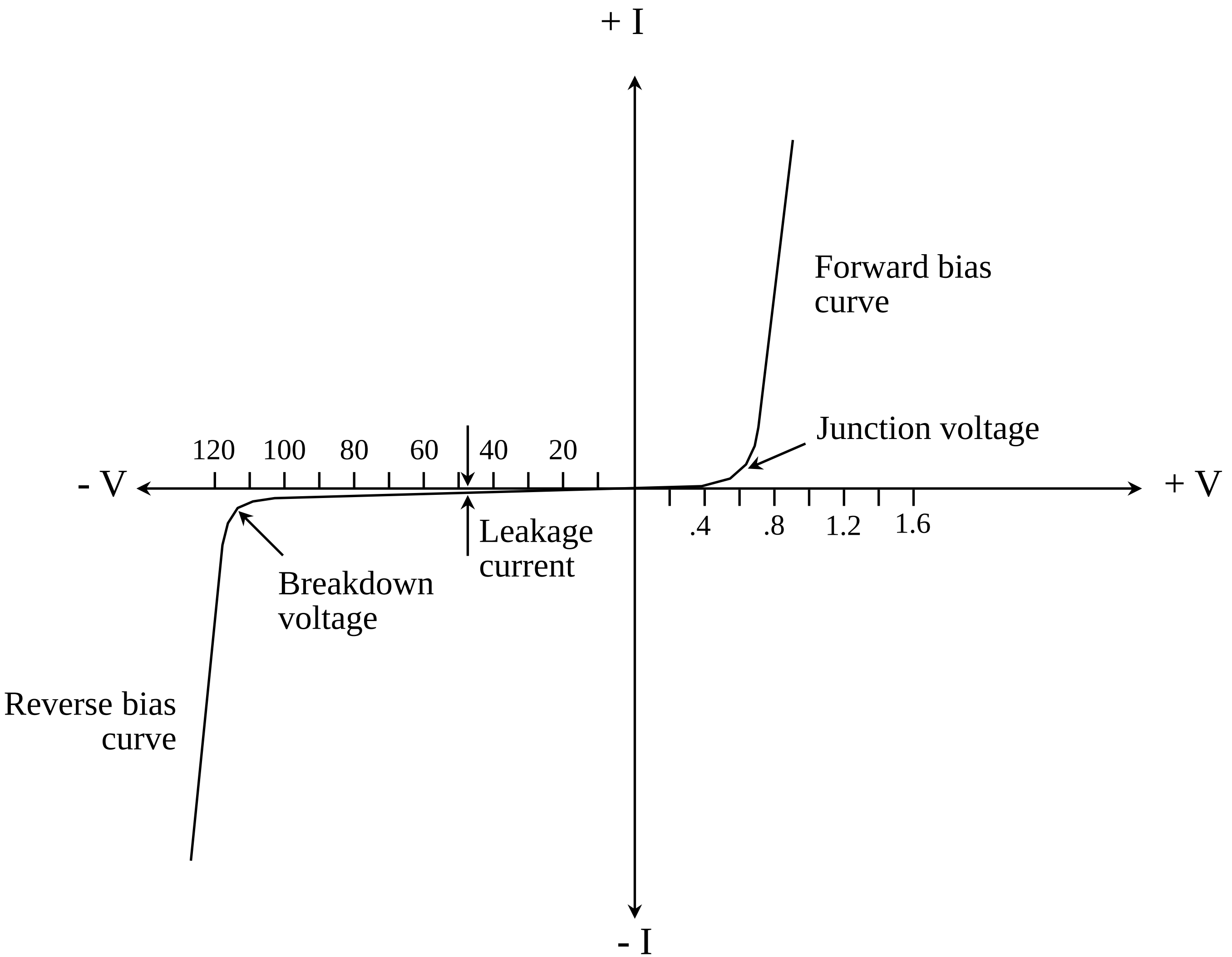
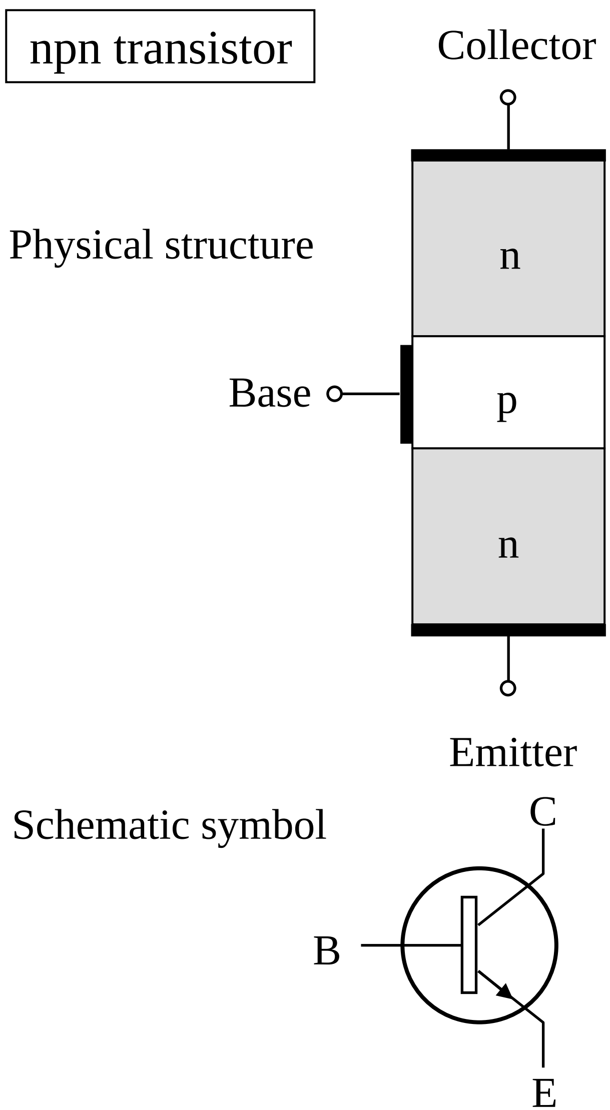
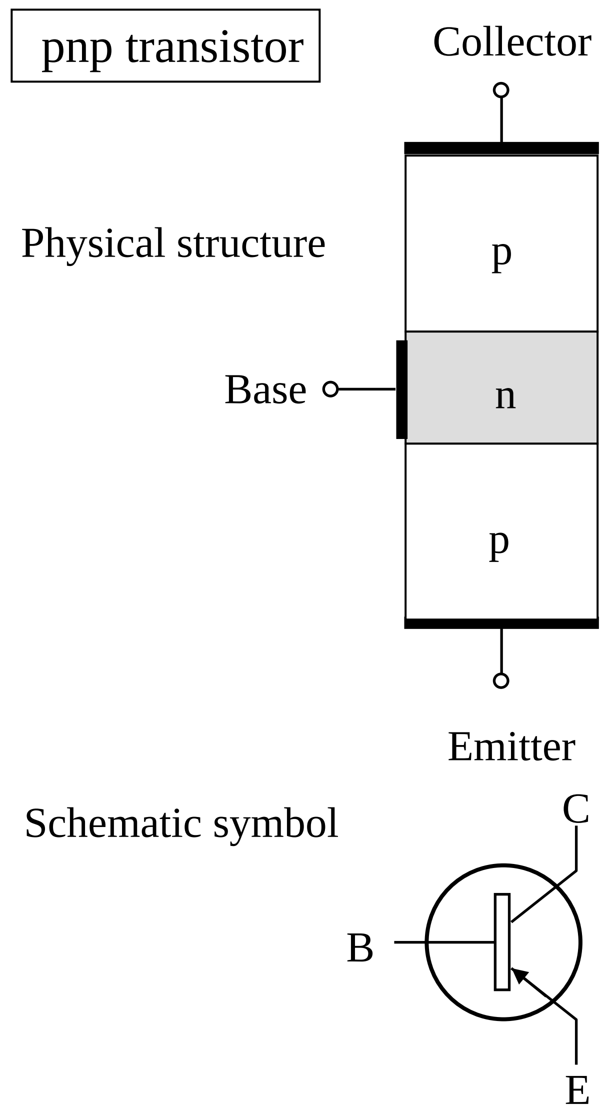


Figure 3.9

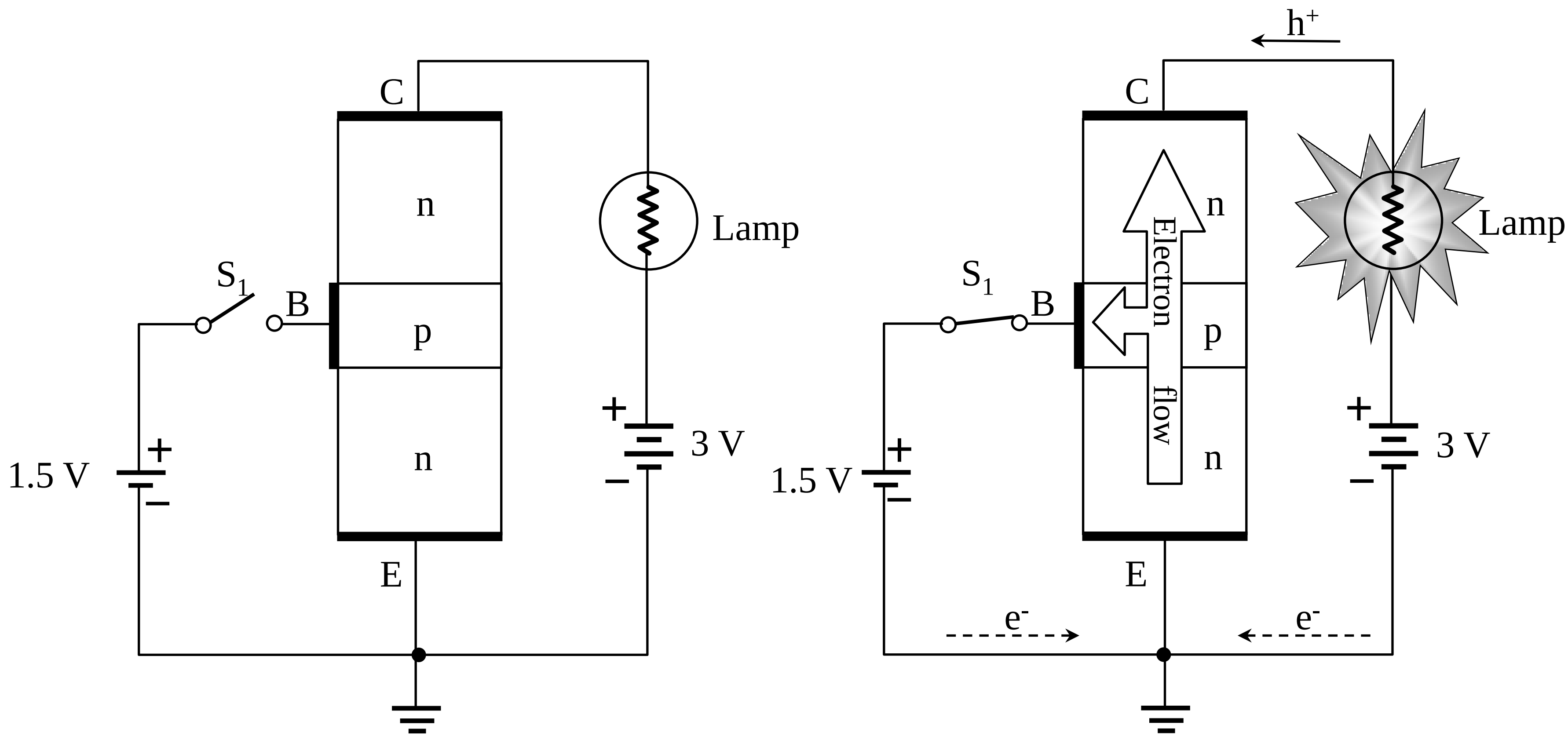
Two Types of Bipolar Transistors





- The emitter arrows indicate the direction of hole or current.

NPN Transistor Biasing Circuit

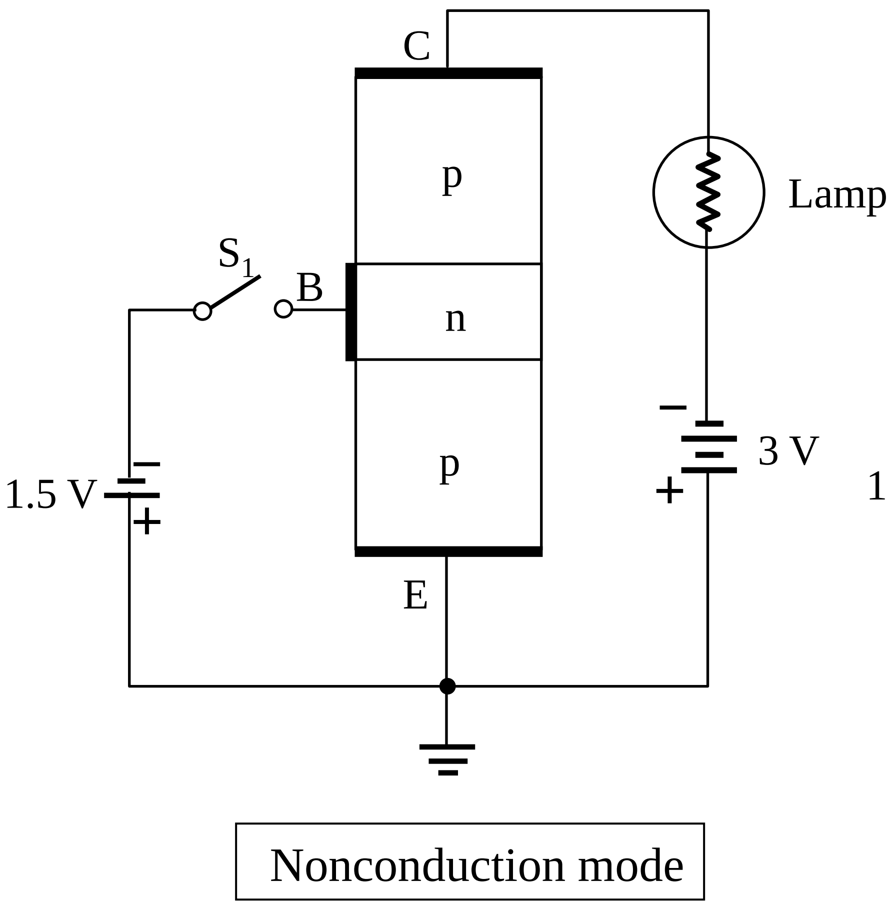


Nonconduction mode

Conduction mode

Figure 3.11

PNP transistor biasing circuit



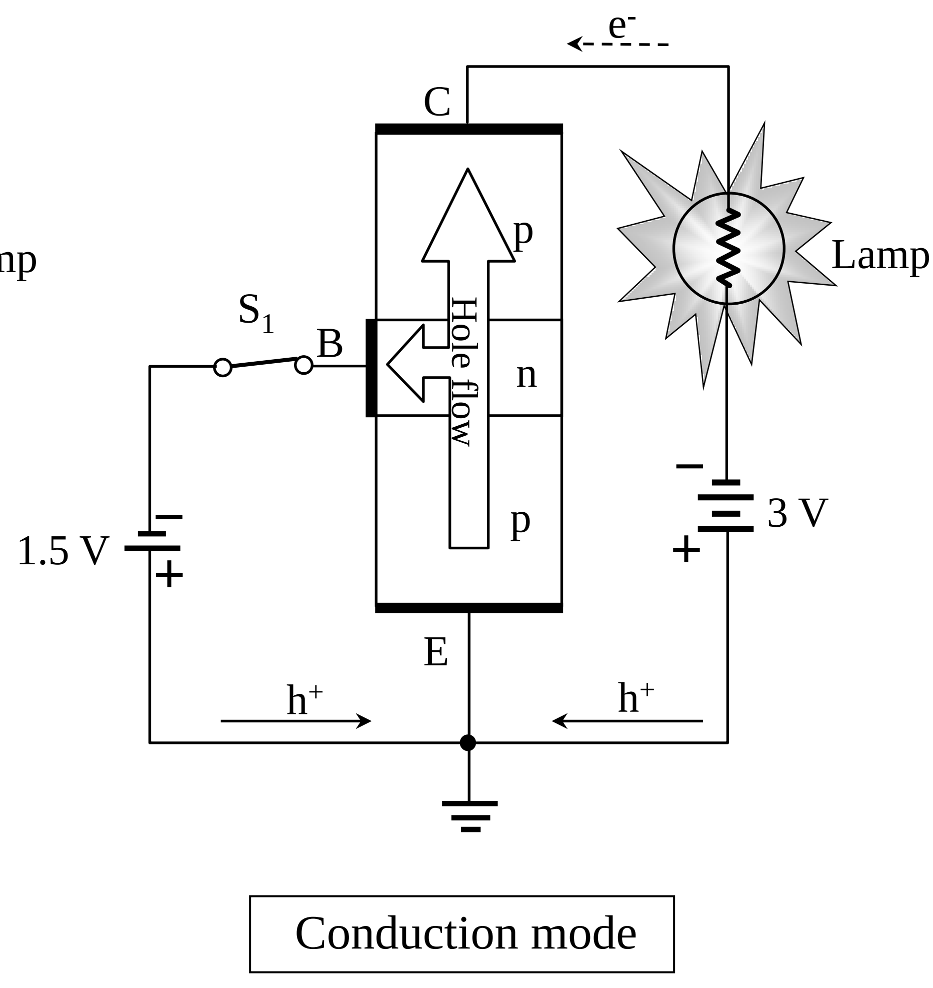


Figure 3.12

Cross Section of an NPN BJT

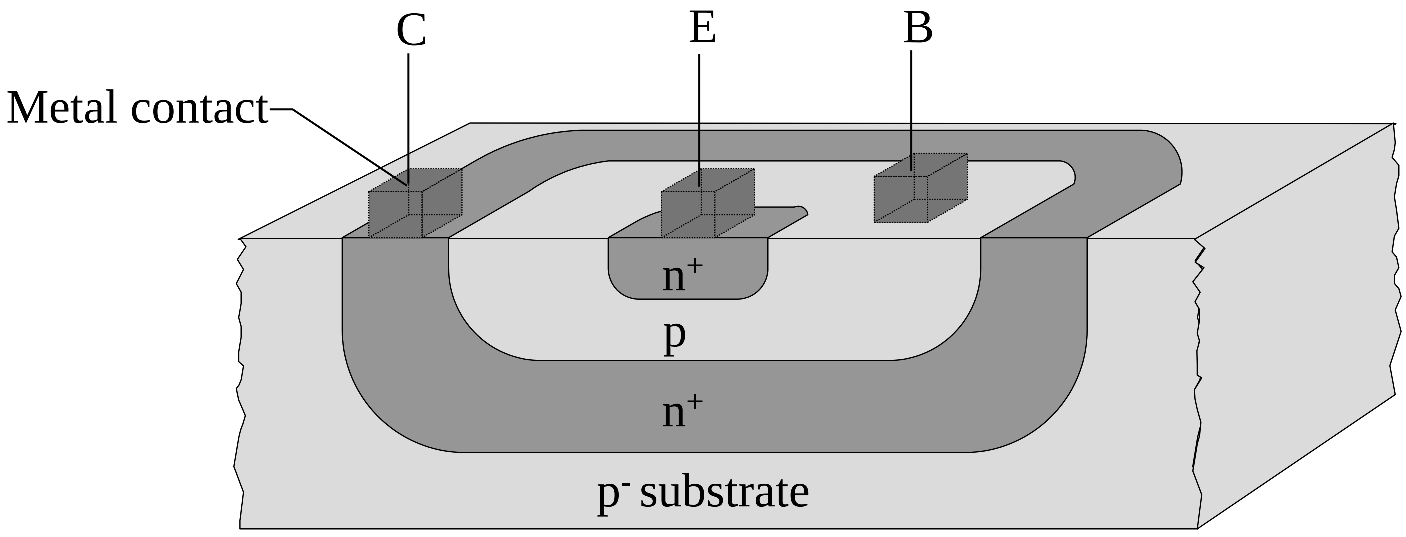
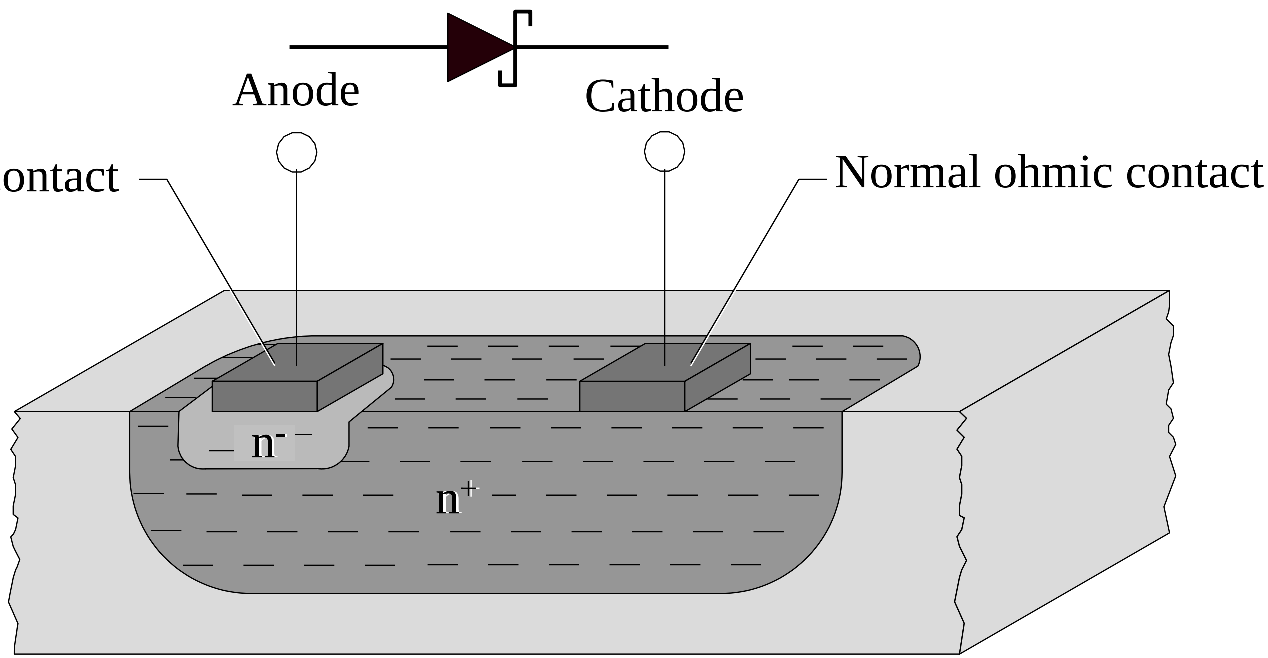


Figure 3.13

Schematic Symbol and Structural Cross Section of the Schottky Diode



- The forward junction voltage drop 0.3~0.5 V is nearly half that of pn-junction 0.6~ 0.8V.
- It formed when metal is brought in contact with lightly doped n-type semiconductor materials.
- Faster switching than pn diode, no minority.

Figure 3.14

Bipolar Logic Families

- It has fast speeds, durability, and power-controlling ability
- The biggest drawback is high power consumption

Table 3.1
Bipolar Logic Families

Bipolar Logic Family	Abbreviation
Direct-Coupled Transistor Logic	DCTL[1]
Resistor-Transistor Logic	RTL[2]
Resistor-Capacitor-Transistor Logic	RCTL[3]
Diode-Transistor Logic	DTL[4]
Transistor-Transistor Logic*	TTL[5]
Schottky TTL Logic*	STTL[6]
Emitter-Coupled Logic*	ECL[7]

[1] G. Deboo and C. Burrous, *Integrated Circuits and Semiconductor Devices: Theory and Application*, 2nd edition, McGraw-Hill, New York, NY, 1977, p. 192.
[2] G. Deboo and C. Burrous, ibid.
[3] G. Deboo and C. Burrous, ibid.
[4] G. Deboo and C. Burrous, ibid.
[5] G. Deboo and C. Burrous, ibid.
[6] A. Sedra, K. Smith, *Microelectronic Circuits*, Oxford University Press, 1998, p. 1187.
[7] A. Sedra, K. Smith, *Microelectronic Circuits*, Oxford University Press, 1998, p. 1196.

BJT vs. MOSFET

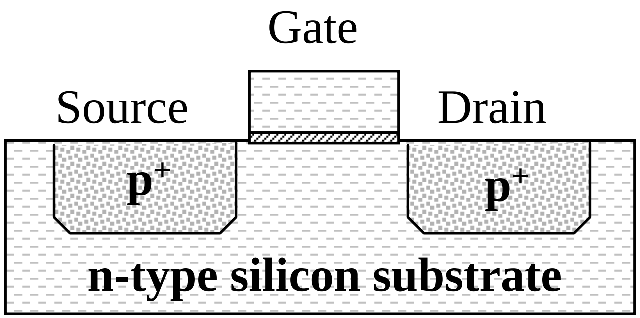
- FET is a voltage-amplifying device, BJT is a current-amplifying device
- Greatest advantage: low voltage and low power operation
- BJT requires input current to turn on, FET as a result of electric field created by gate voltage- thus the name field-effect transistor
- It has infinite R_{in} and moderate gain make it an excellent device for use in instrumentation and communications.

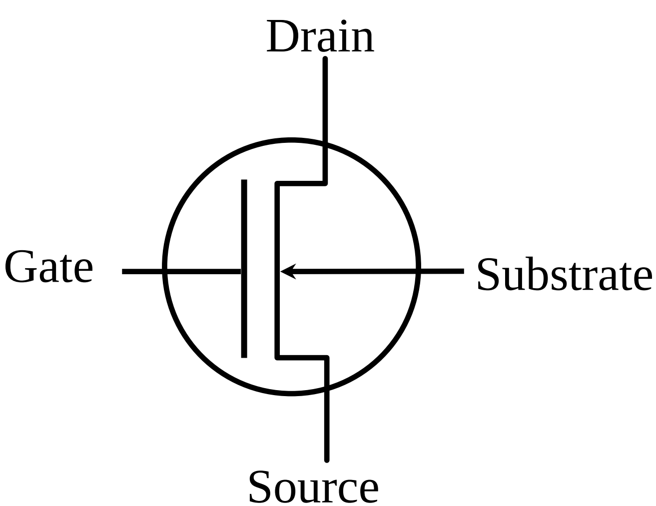
CMOS IC Technology

- The Field Effect Transistor (less power)
  - MOSFETs
    - nMOSFET
    - pMOSFET
  - Biasing the nMOSFET
  - Biasing the pMOSFET
- CMOS Technology
- BiCMOS Technology
- Enhancement and Depletion-Mode

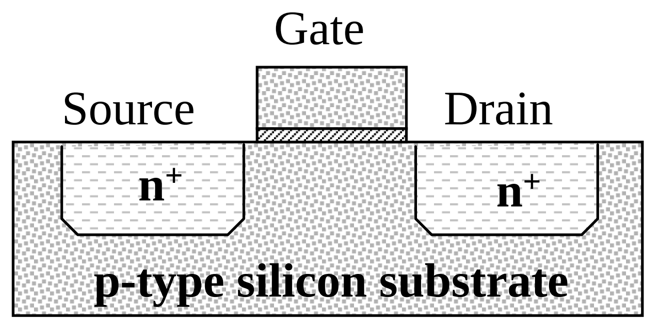
Two Types of MOSFETs

pMOSFET (p-channel)





nMOSFET (n-channel)



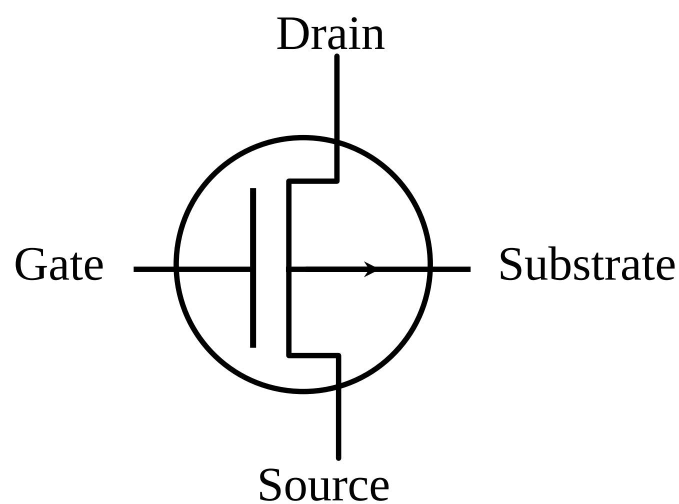


Figure 3.15

Biasing Circuit for an NMOS Transistor

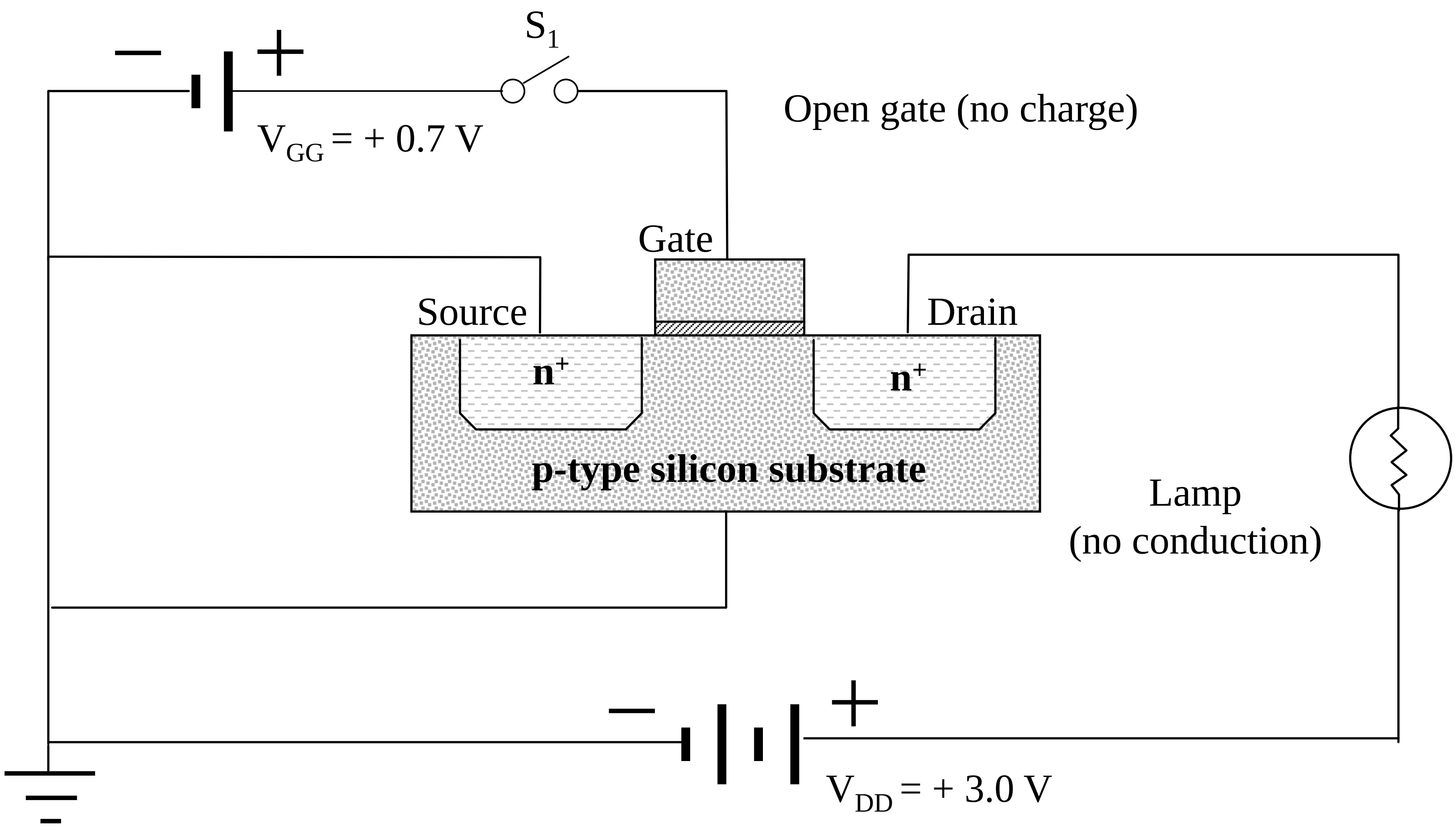


Figure 3.16

NMOS Transistor in Conduction Mode

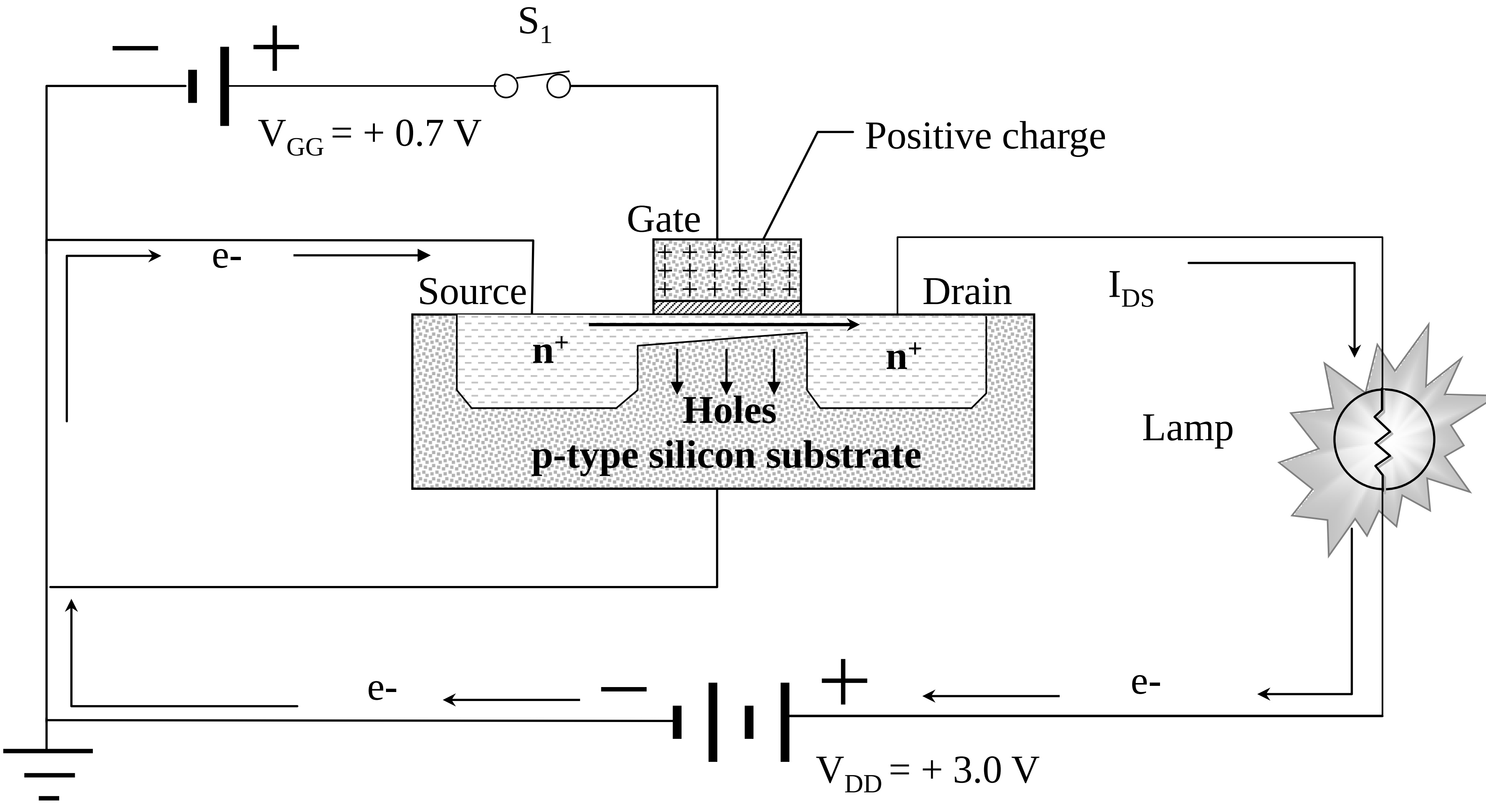


Figure 3.17

Example of Characteristics Curves of an N-channel MOSFET

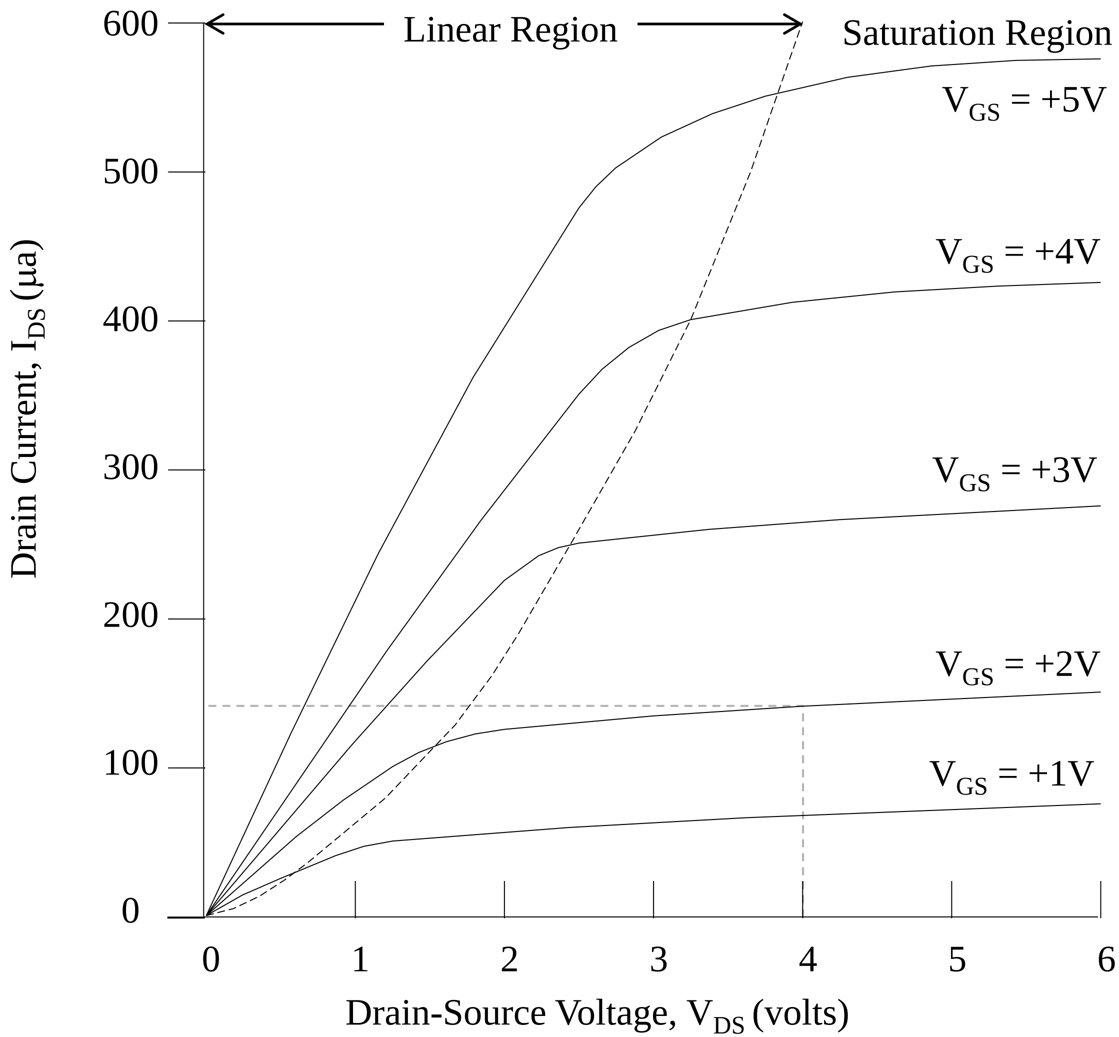


Figure 3.18

Biasing Circuit for a P-Channel MOSFET

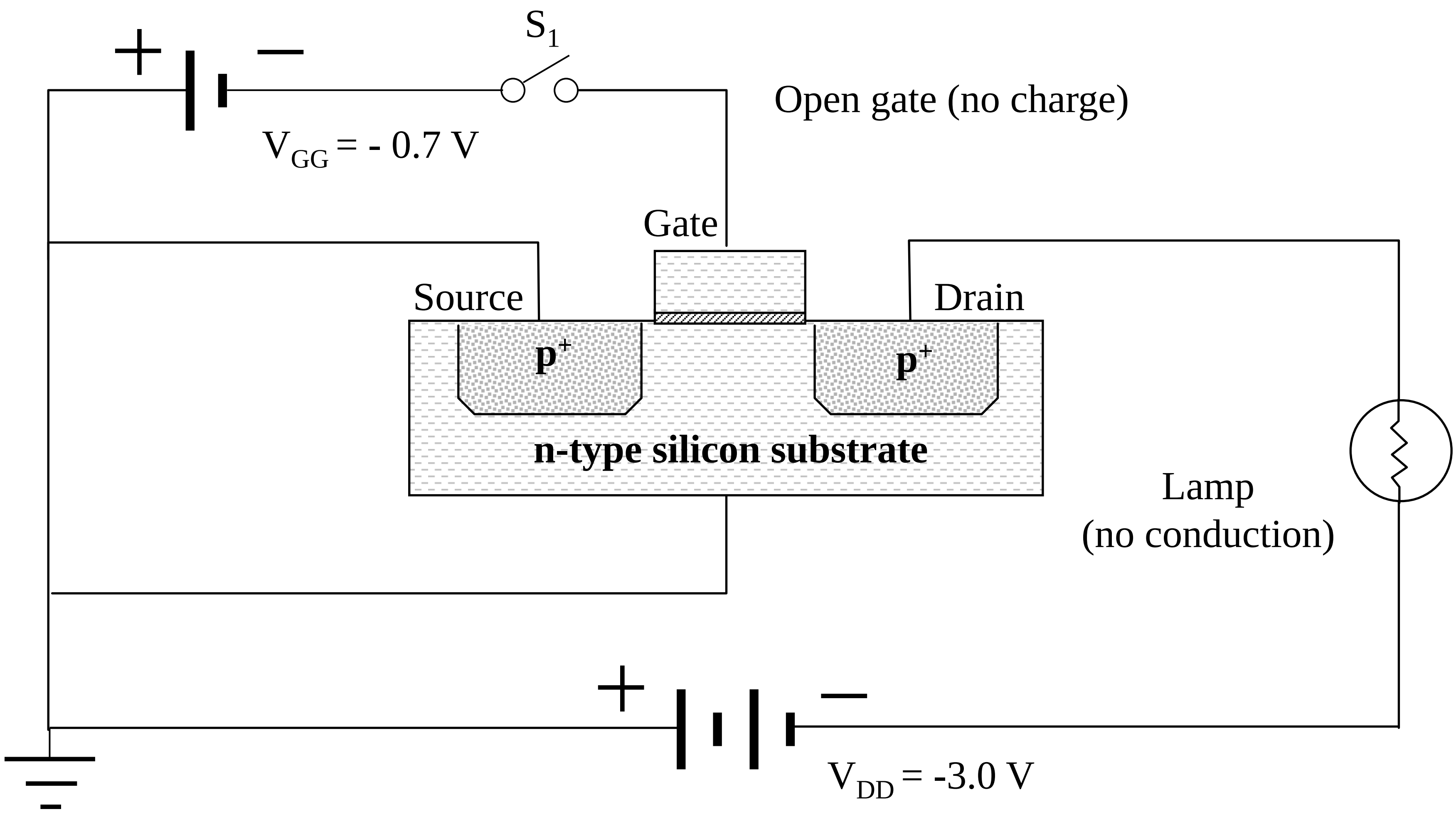


Figure 3.19

PMOS Transistor in Conduction Mode

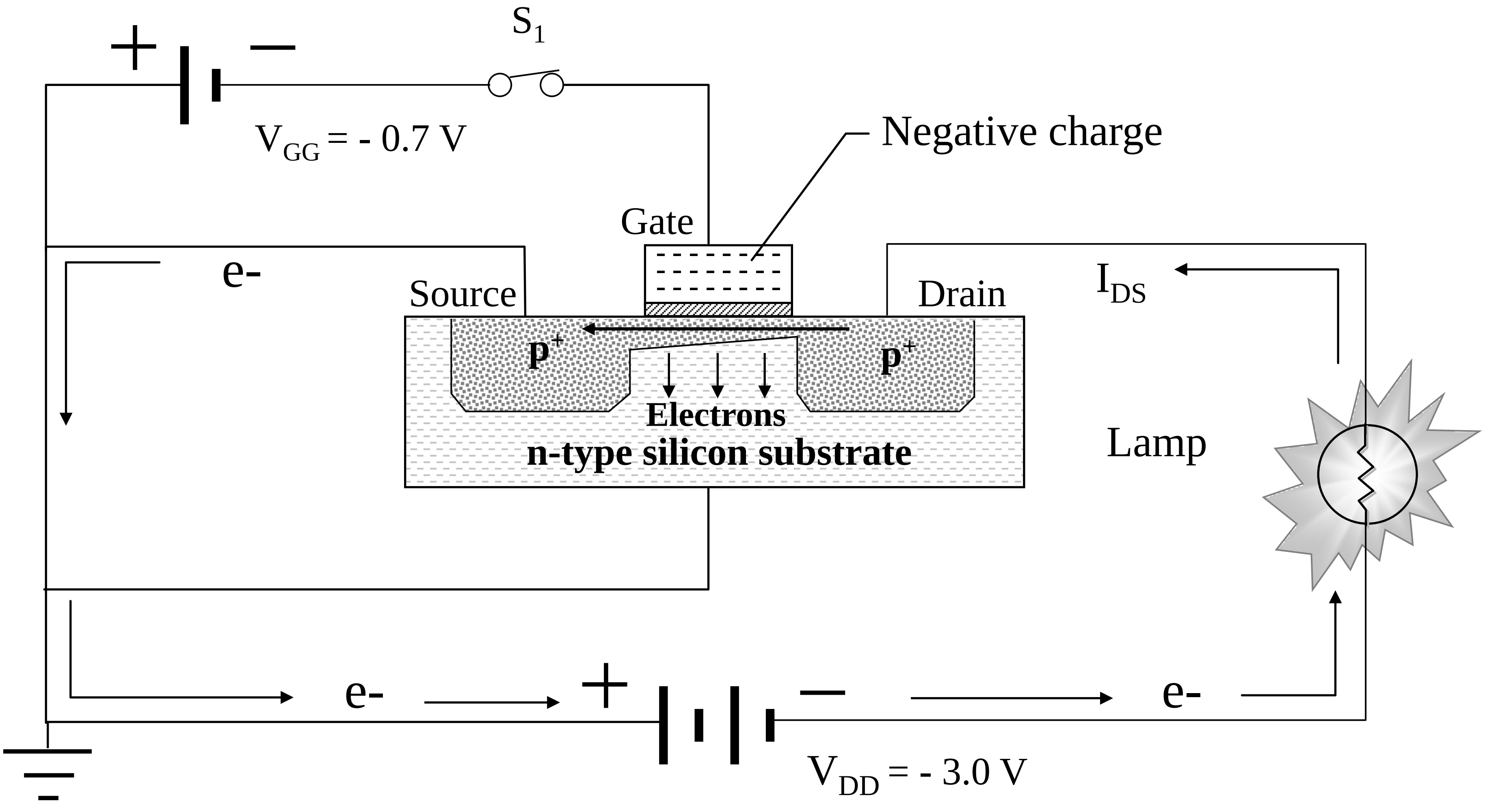


Figure 3.20

Schematic of a CMOS Inverter

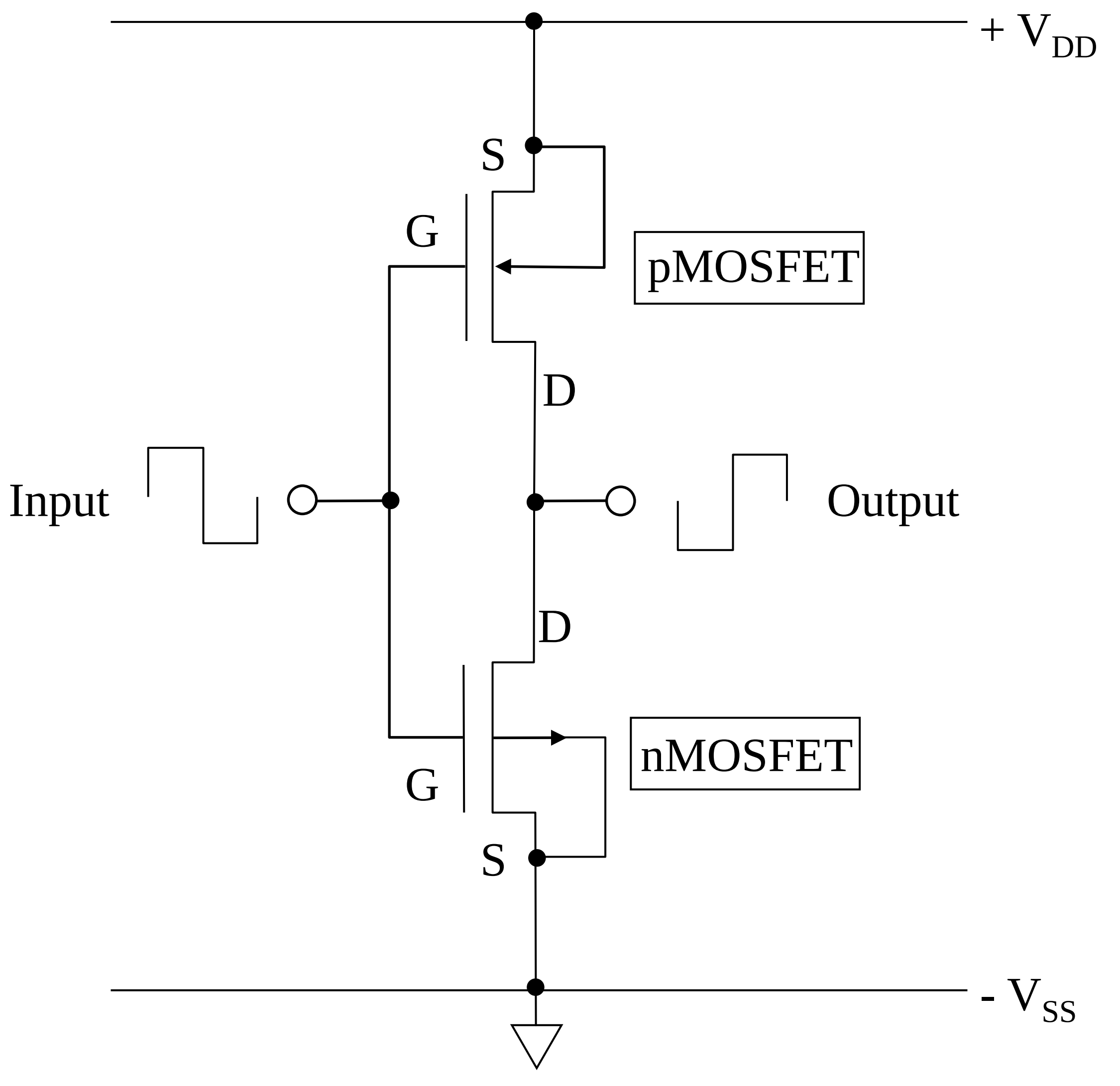


Figure 3.21

Top View of CMOS Inverter

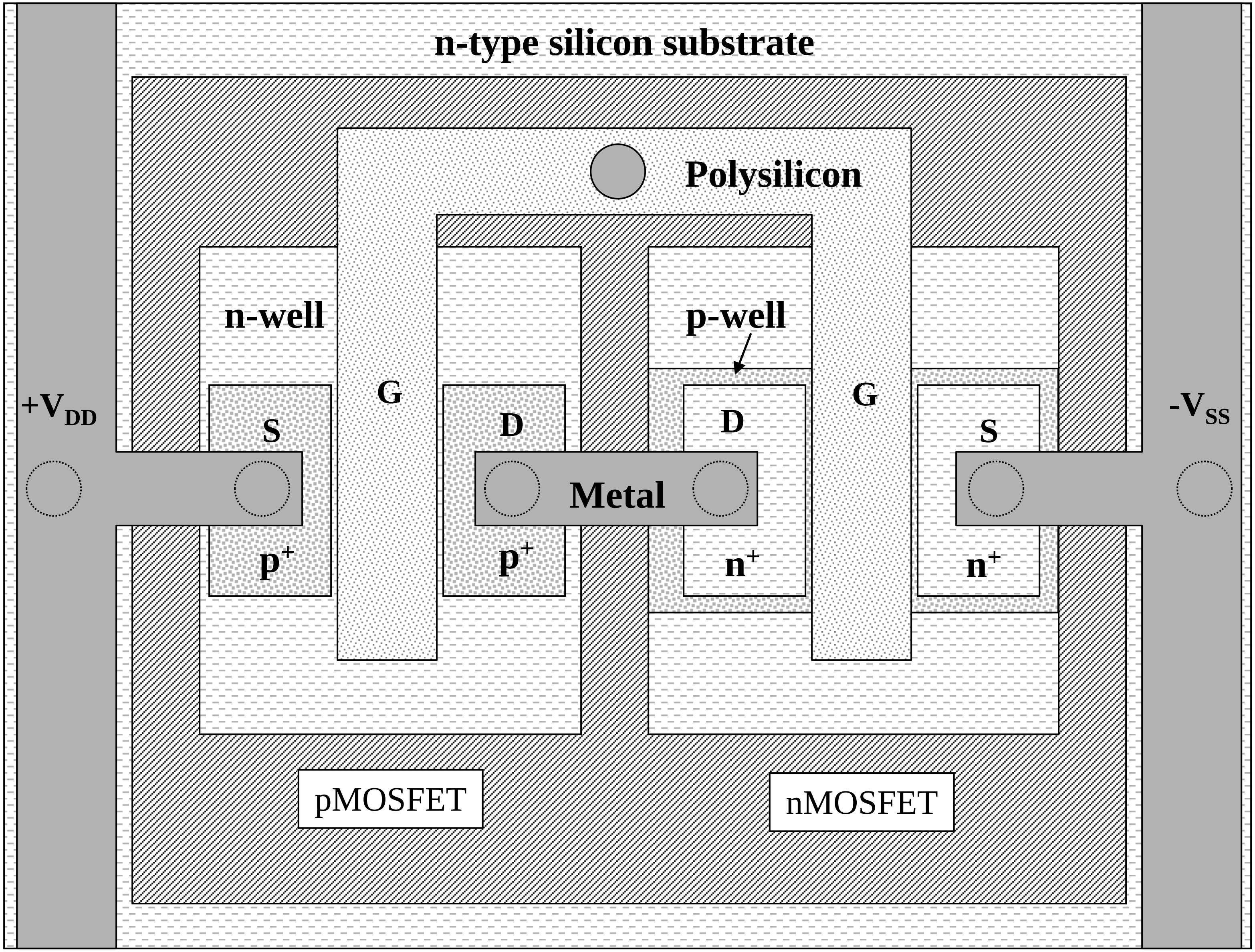


Figure 3.22

Cross-section of CMOS Inverter

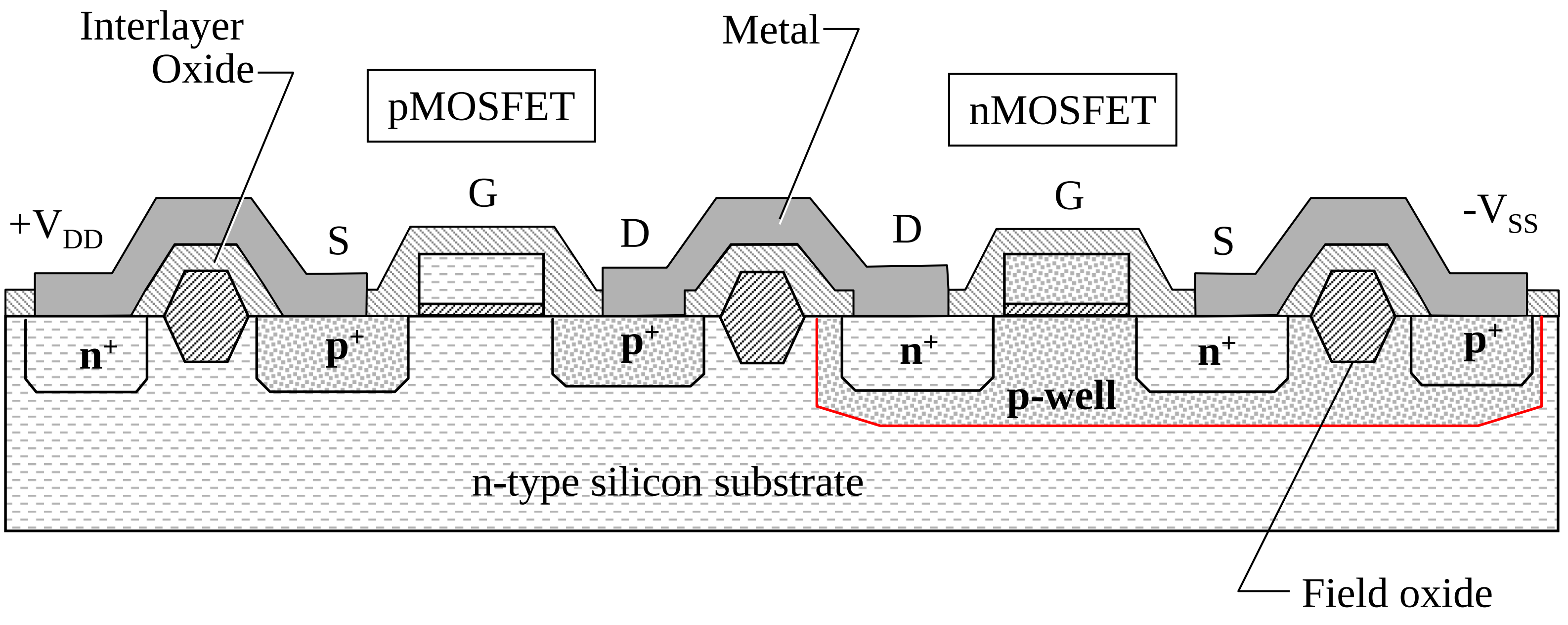


Figure 3.23

BiCMOS Chips used in the Control of a Simple Heating System

- BiCMOS technology makes use of the best feature of both CMOS and bipolar technology.
- BiCMOS incorporates the low-power, high-density CMOS with high current drive capability of BJT.

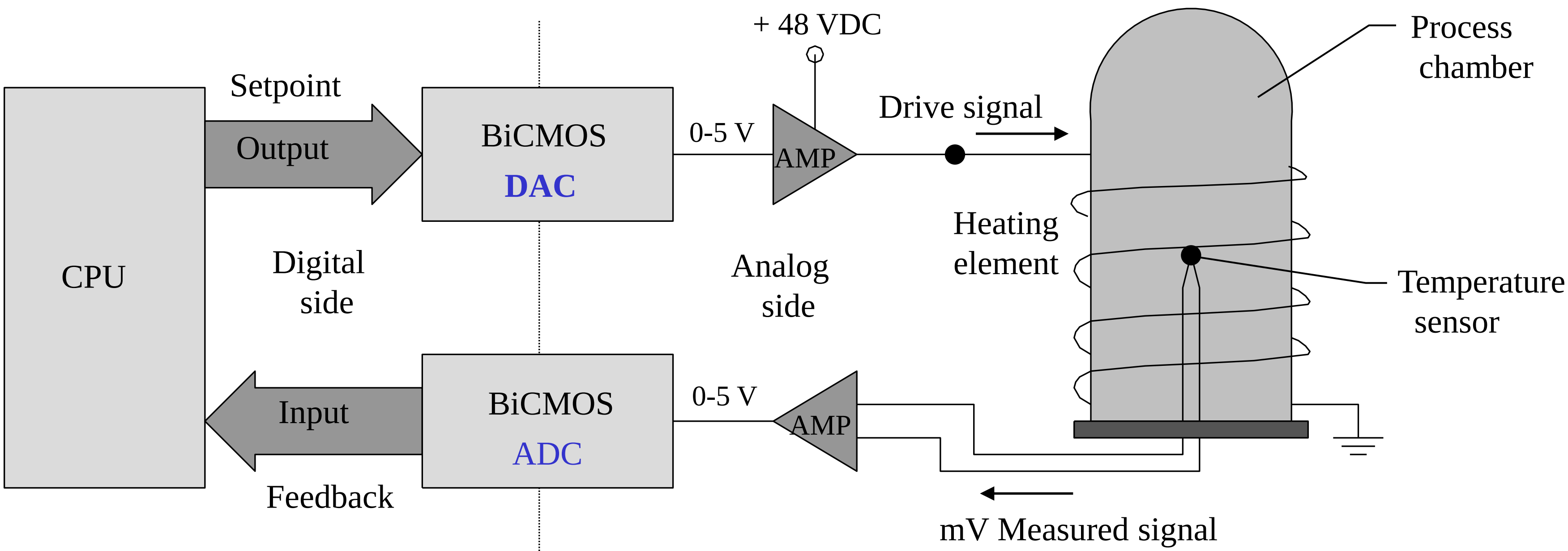
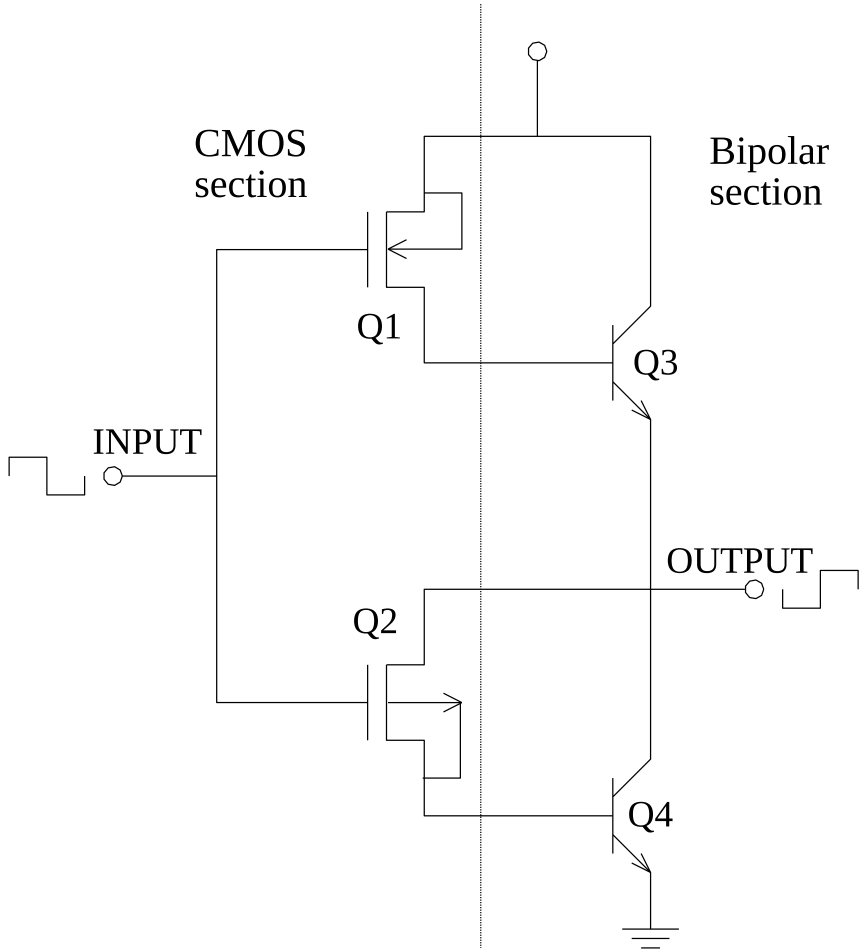


Figure 3.24

Simple BiCMOS Inverter



Redrawn from H. Lin, J. Ho, R. Iyer, and K. Kwong, “Complementary MOS-Bipolar Transistor Structure,” *IEEE Transactions Electron Devices*, ED-16, 11 Nov. 1969, p. 945 - 951.

Figure 3.25

Comparison of Enhancement and Depletion Mode MOSFETs

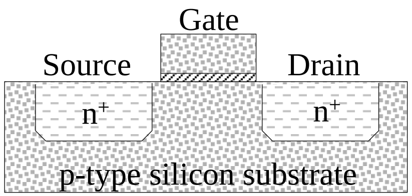
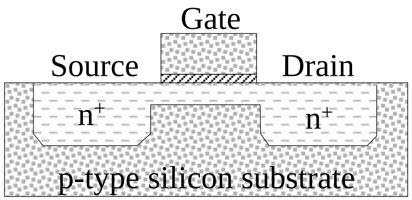
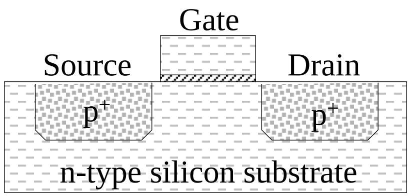
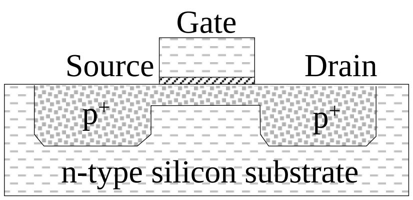
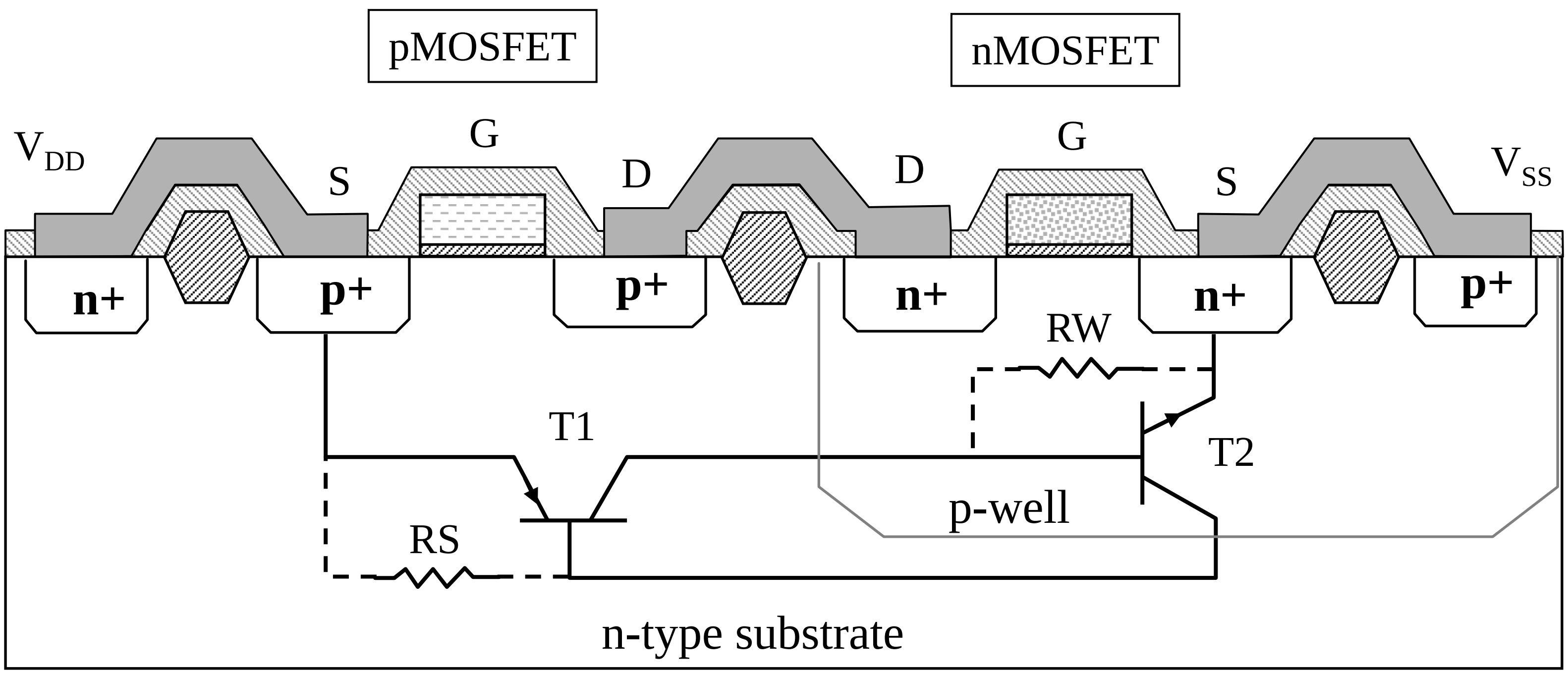
MOSFET Type	Mode	Standby Condition	V_{GG} Switching Requirements	Physical Structure
nMOS	Enhancement	Off	+	
nMOS	Depletion	On	-	
pMOS	Enhancement	Off	-	
pMOS	Depletion	On	+	

Figure 3.26

Latchup in CMOS Devices



Parasitic Junction Transistors within a CMOS Structure

Figure 3.27

Integrated Circuit Products

- Linear IC Products
  - Operational Amplifier
  - Voltage Regulator
  - Stepper Motor Driver

- Digital IC Products
  - Volatile Memory
    - RAM
    - DRAM
    - SRAM
    - MPU or CPU

- Digital IC Products (continued)
  - Nonvolatile Memory
    - ROM
    - PROM
    - EPROM
    - EEPROM
    - ASIC
    - PLD
    - PAL
    - PLA
    - MPGA
    - FPGA