

FACULDADE DE TECNOLOGIA DE SÃO PAULO FATEC - SP

CURSO SUPERIOR DE MATERIAIS, PROCESSOS E
COMPONENTES ELETRÔNICOS - MPCE

DISPOSITIVOS SEMICONDUTORES II - DS II

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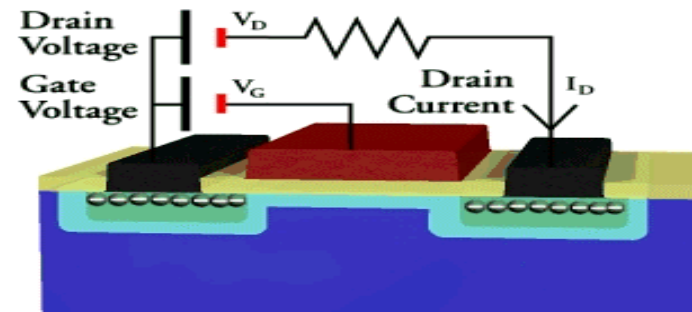
Prof. Marcelo Bariatto

OBJETIVO

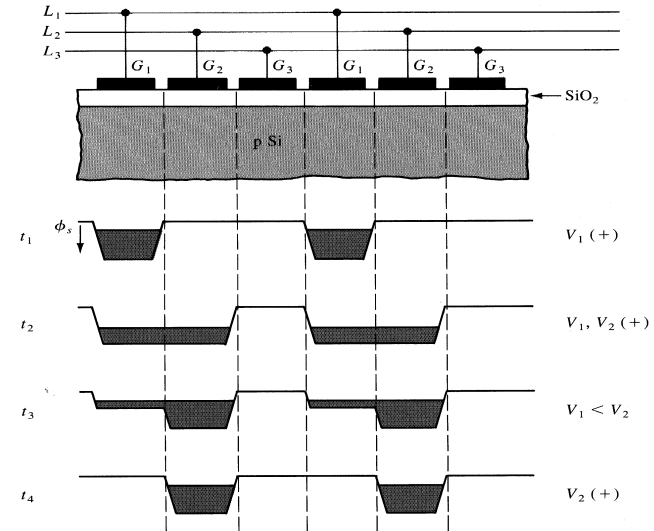
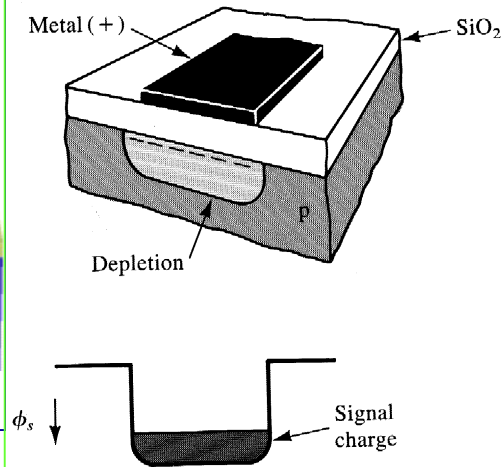
- Estudar os aspectos físicos, tecnológicos e elétricos associados aos dispositivos semicondutores em silício, especificamente ao capacitor MOS (Metal Óxido Semicondutor) e ao transistor MOS.

Aplicações MOS

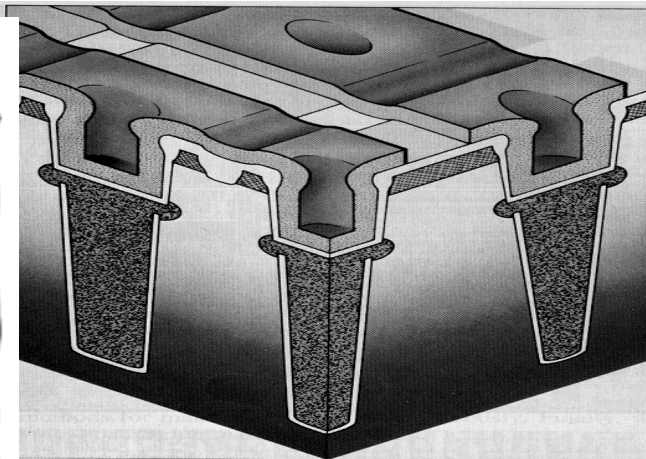
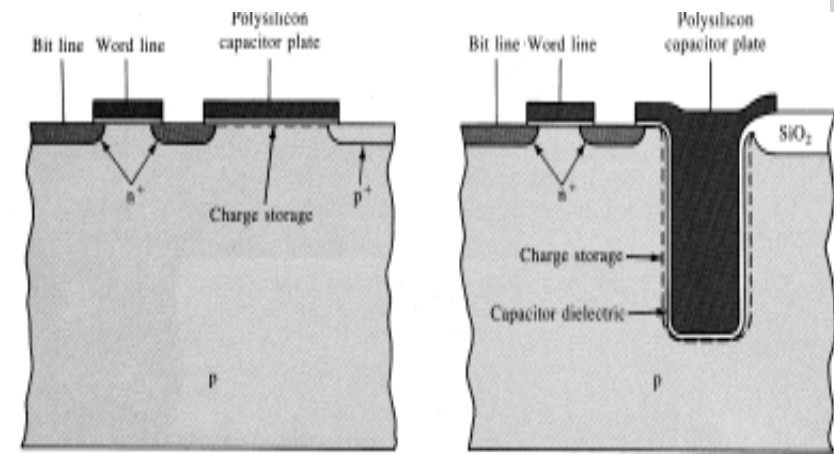
TRANSISTOR MOS



CCD's



DRAM



Conteúdo programático

- 1. Apresentação / Revisão
- 2. Diagrama de Bandas de Energia
- 3. Capacitor MOS
- 4. Regime de cargas no capacitor MOS
- 5. Regime de cargas no capacitor MOS (cont.)
- 6. Curva capacitância x tensão (C-V)
- 7. **PROVA P1**
- 8. Transistor MOS
- 9. Transistor MOS (cont.)

**2 AVALIAÇÕES EM
SALA (15 MIN.)**

Conteúdo programático - cont.

- 10. Regiões de operação do transistor MOS
- 11. Características Elétricas do transistor MOS
- 12. Tensão de limiar
- 13. Extração de parâmetros elétricos
- 14. Efeito de canal curto
- 15. Efeito de perfuração MOS e estrutura LDD
- 16. Efeito de canal estreito
- 17. PROVA P2
- 18. SUBSTITUTIVA/EXAME

**2 AVALIAÇÕES EM
SALA (15 MIN.)**

CRITÉRIO DE AVALIAÇÃO

■ Provas: **P1, P2**

■ Média:

$$M = (0,4 \times P1 + 0,6 \times P2) \times 0,9 + EX$$

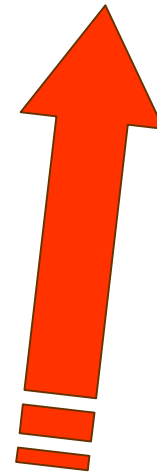
$$EX = \text{MÉDIA AVAL. (0 - 1,0)}$$

$M < 5,0 \rightarrow \text{C, REPROVADO}$

$5,0 \leq M < 7,0 \rightarrow \text{B, APROVADO}$

$7,0 \leq M < 8,5 \rightarrow \text{A, APROVADO}$

$8,5 \leq M \leq 10,0 \rightarrow \text{E, APROVADO}$



■ Prova substitutiva

■ Exame $\rightarrow (M + P_{EX.})/2$ **TODA MATÉRIA**

■ AVALIAÇÃO SUBSTITUTIVA

BIBLIOGRAFIA

■ Básica

- Solid State Electronic Devices, Streetman
- Field Effect Devices - Modular Series on Solid State Devices vol. IV, Robert Pierret
- Device Electronics for Integrated Circuits, Muller and Kamis

■ Complementar

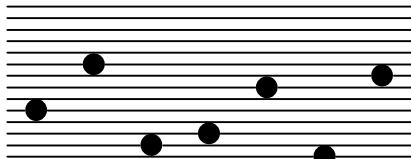
- Physics of Semiconductor Devices, Sze
- Understanding Semiconductor Devices, Dimitrijevic

- Internet: <http://schof.Colorado.EDU/~bart/book/start.htm>
<http://jas2.eng.buffalo.edu/applets/>

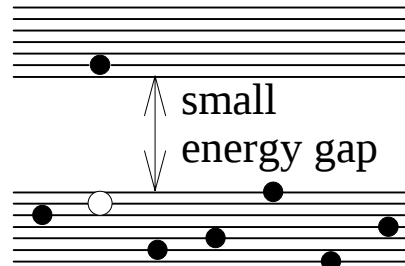
1. REVISÃO / SEMICONDUTORES

Metal, semicondutor e isolante

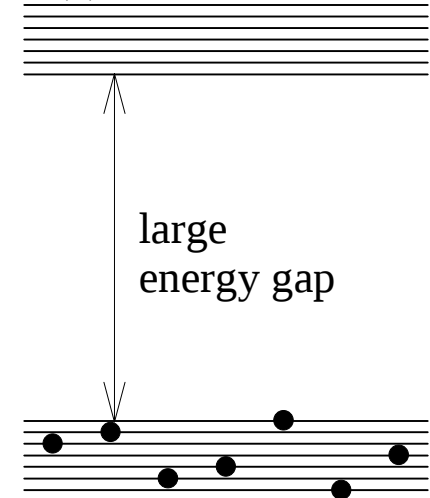
(a) metal



(b) semiconductor



(c) insulator



$$E_g (\text{Si}) = 1,1 \text{ eV}$$

$$E_g (\text{Ge}) = 0,67 \text{ eV}$$

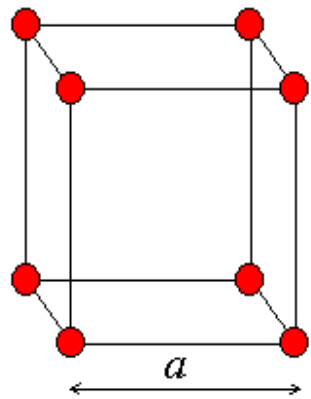
$$E_g (\text{GaAs}) = 1,43 \text{ eV}$$

$$E_g (\text{SiO}_2) \sim 8 \text{ eV}$$

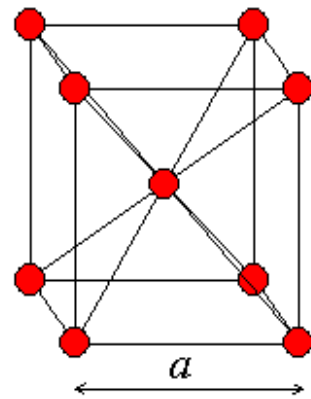
$$T = 300 \text{ K}$$

Semicondutor (Si)

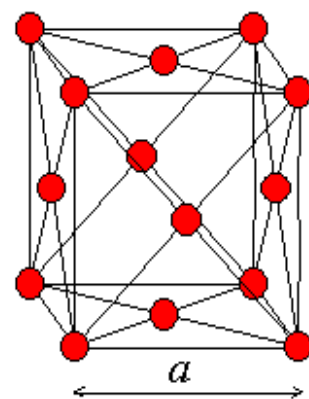
■ Estrutura cristalina - tetraédrica



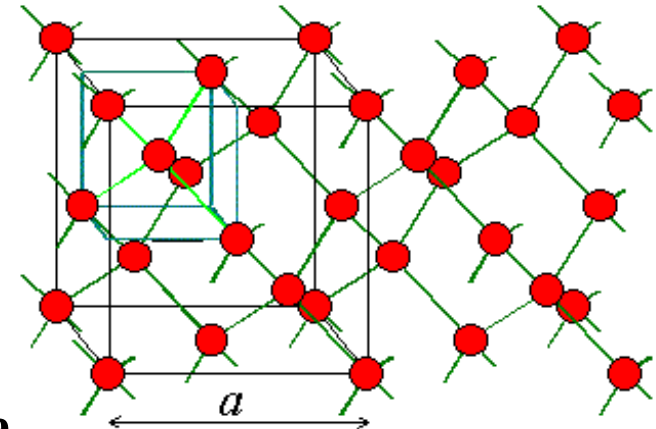
cúbica simples
(sc)



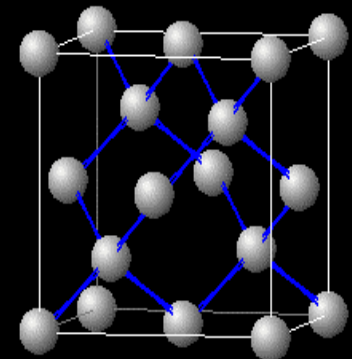
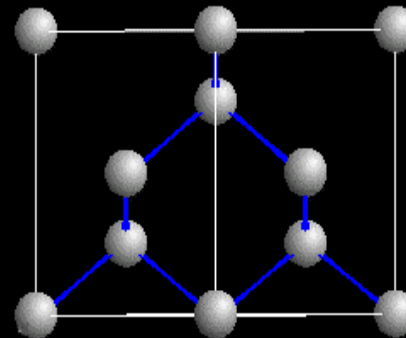
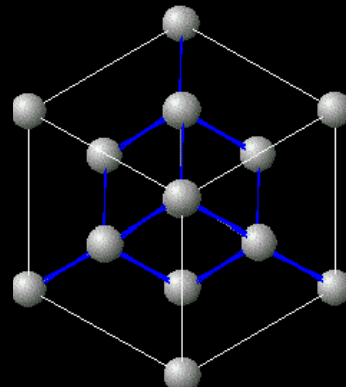
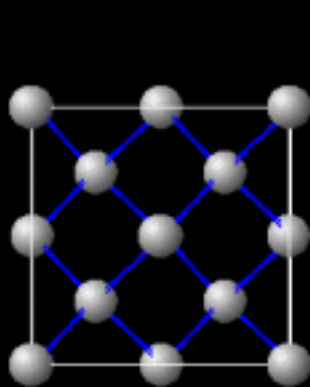
cúbica de corpo
centrado (bcc)



cúbica de face
centrada (fcc)



tetraédrica

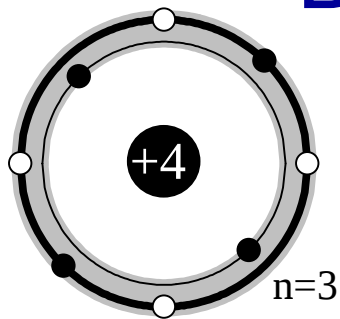


Propriedades principais

Atoms/cm ³	5.0E22	Atomic Weight	28.09
Breakdown field (V/cm)	~3E5	Crystal structure	Diamond
Density (g/cm ³)	2.328	Dielectric Constant	11.9
N _c (cm ⁻³)	2.8E19	N _v (cm ⁻³)	1.04E19
Effective Mass, m [*] /m ₀		Electron affinity, χ (V)	4.15
Electrons		Energy gap (eV) at 300K	1.1
m [*] _l 0.98			
m [*] _l 0.19			
Holes		Intrinsic carrier conc. (cm ⁻³)	1.45E10
m [*] _{eh} 0.16		Intrinsic Debye Length (um)	24
m [*] _{hh} 0.49			
Intrinsic resistivity (-cm)	2.3E5	Melting point (C)	1415
Lattice constant (A)	5.43095	Optical-phonon energy (eV)	0.063
Linear coefficient of thermal expansion, L/LT(C-1)	2.6E-6	Specific heat (J/g C)	0.7
Minority carrier lifetime (s)	2.5E-3	Thermal conductivity (W/cmC)	1.5
Mobility (drift) (cm ² /V-8)		Thermal diffusivity (cm ² /s)	0.9
1500 (electron)		Vapor pressure (Pa)	1 at 1650C
450 (hole)			1E-6 at 900 C
Phonon mean free path (A)			
76(electron)			
55(hole)			

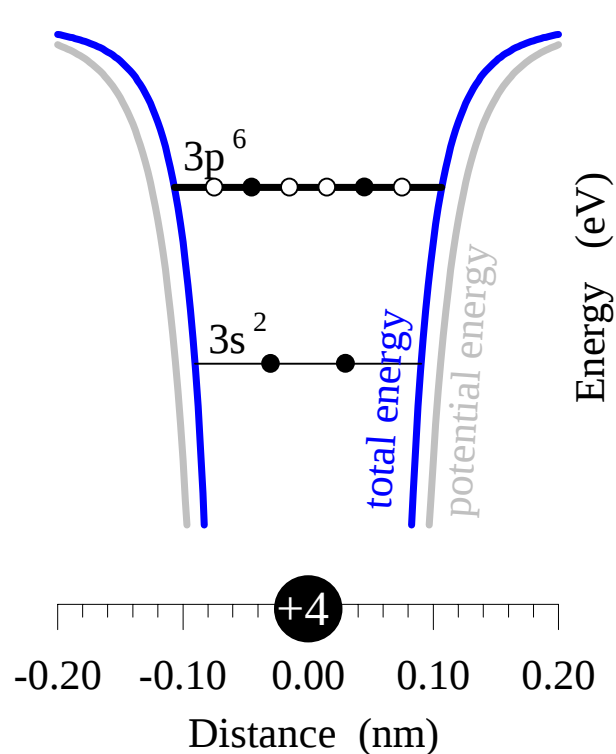
Diagrama de bandas do Si

(a)

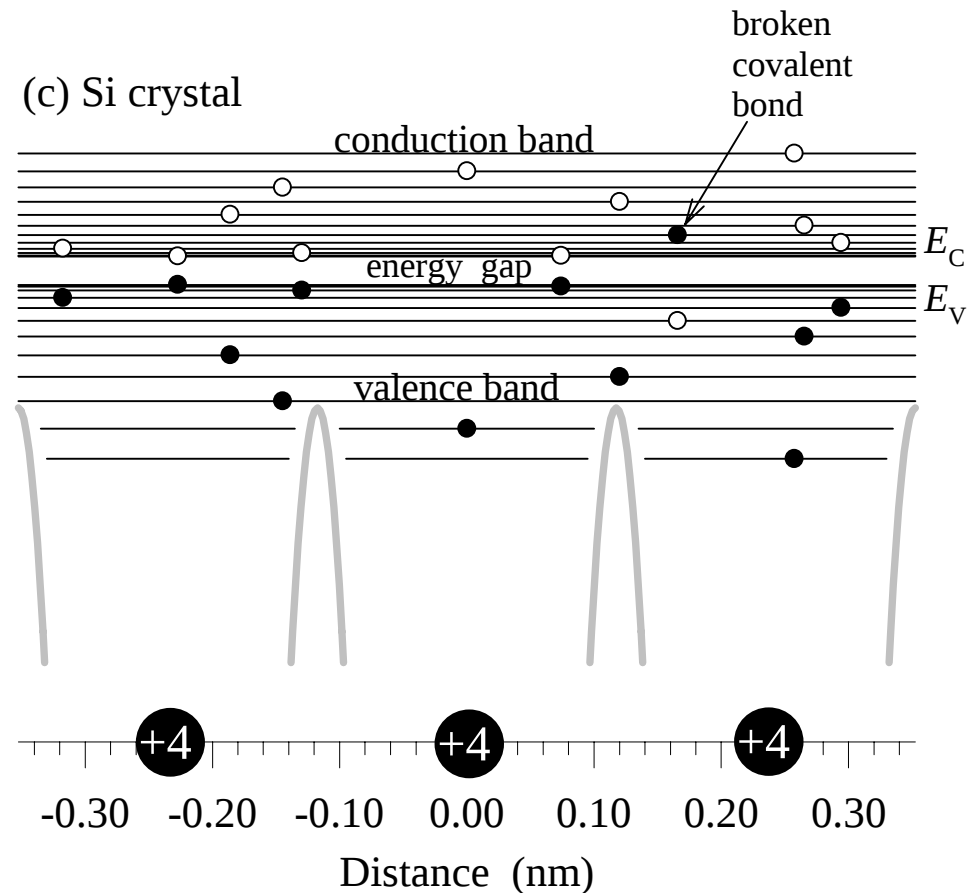


- filled electron state
- empty electron state

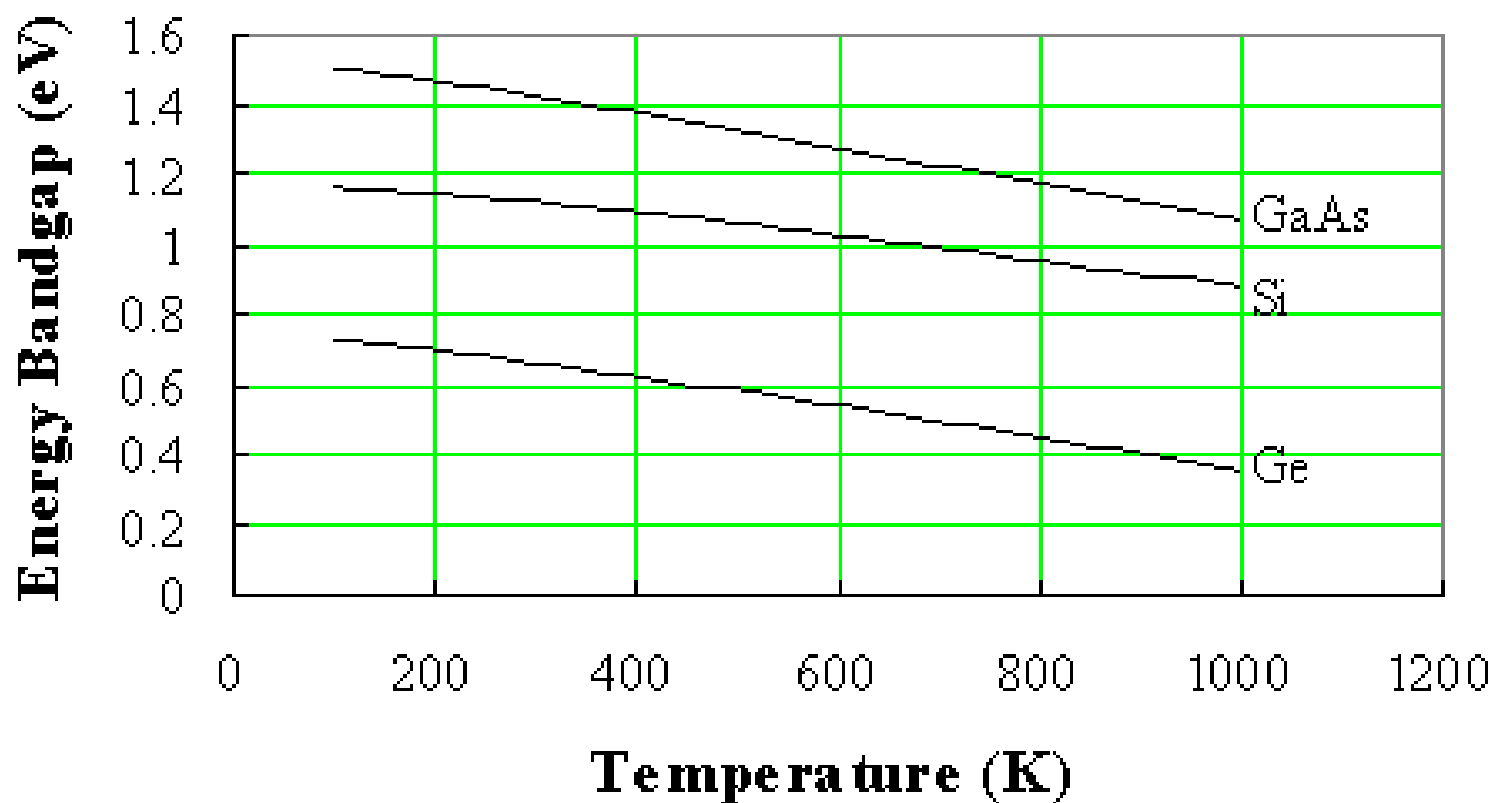
(b) Si atom



(c) Si crystal

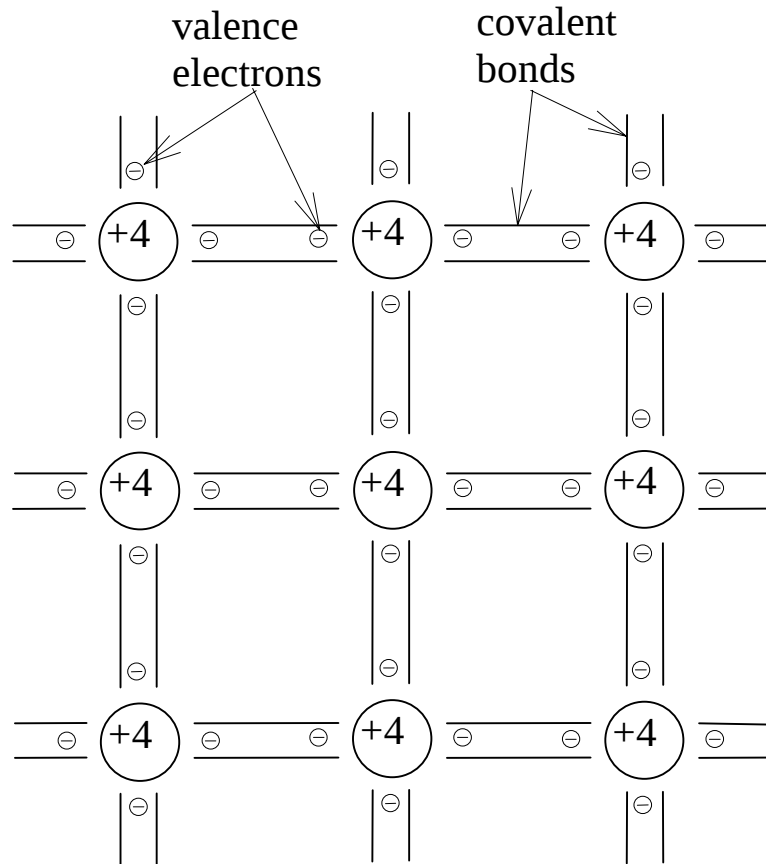


Dependência $E(g) = f(T)$



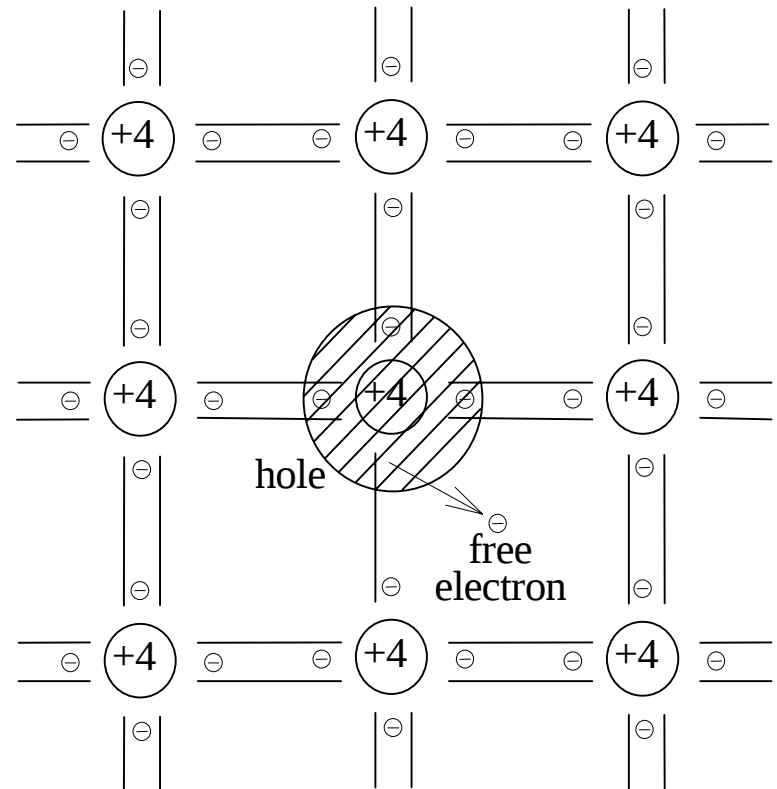
Semicondutor intrínseco

(a)



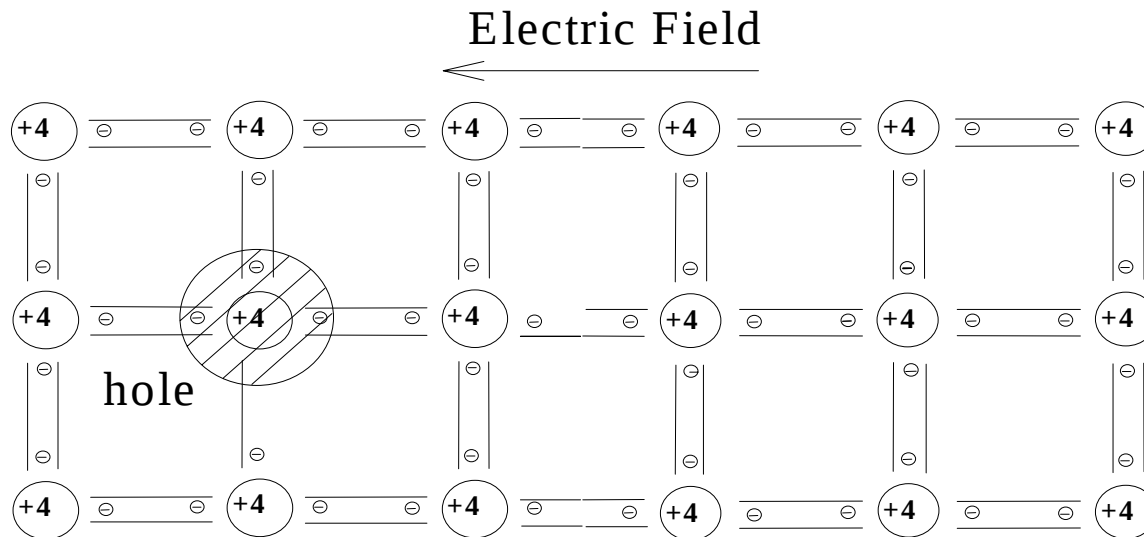
$T = 0 \text{ K}$

(b)



$T > 0 \text{ K}$

Semicondutor intrínseco (cont.)

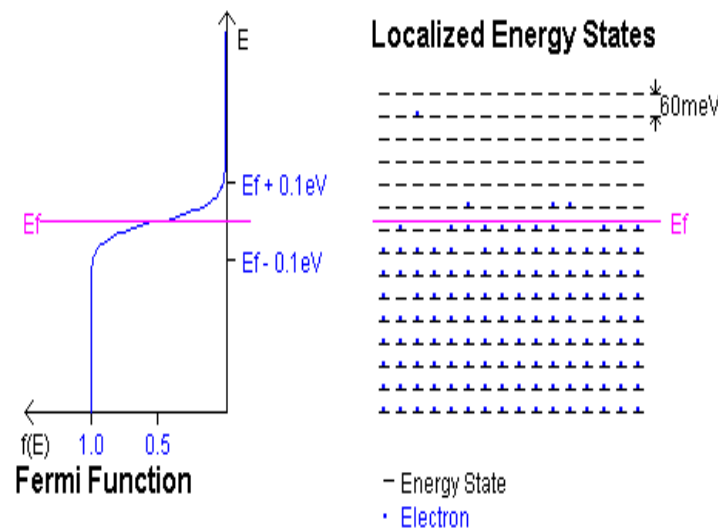
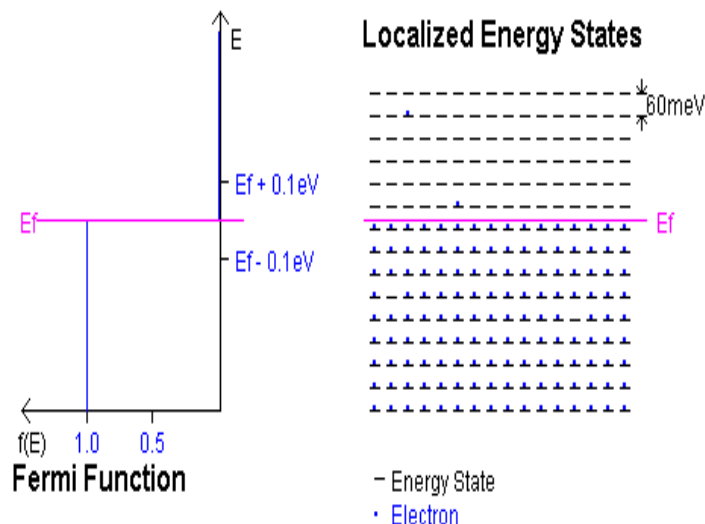


Nível de Fermi

Indica o nível de energia cuja probabilidade de ocupação é 50 %

■ Energia de Fermi

– máxima energia de um elétron no estado fundamental



Temperature = 0.0K



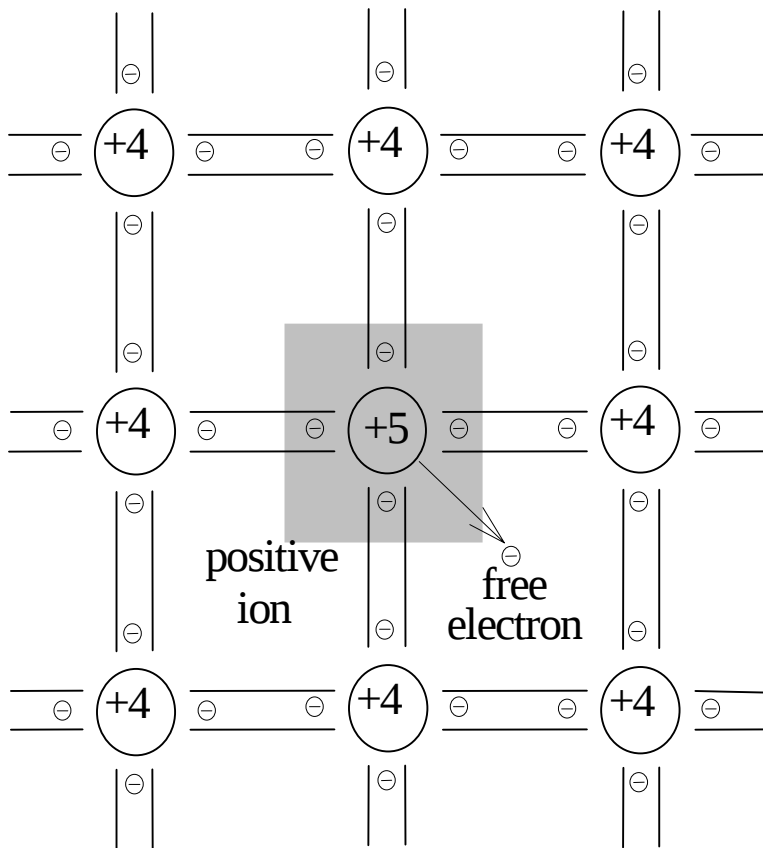
Temperature = 299.0K



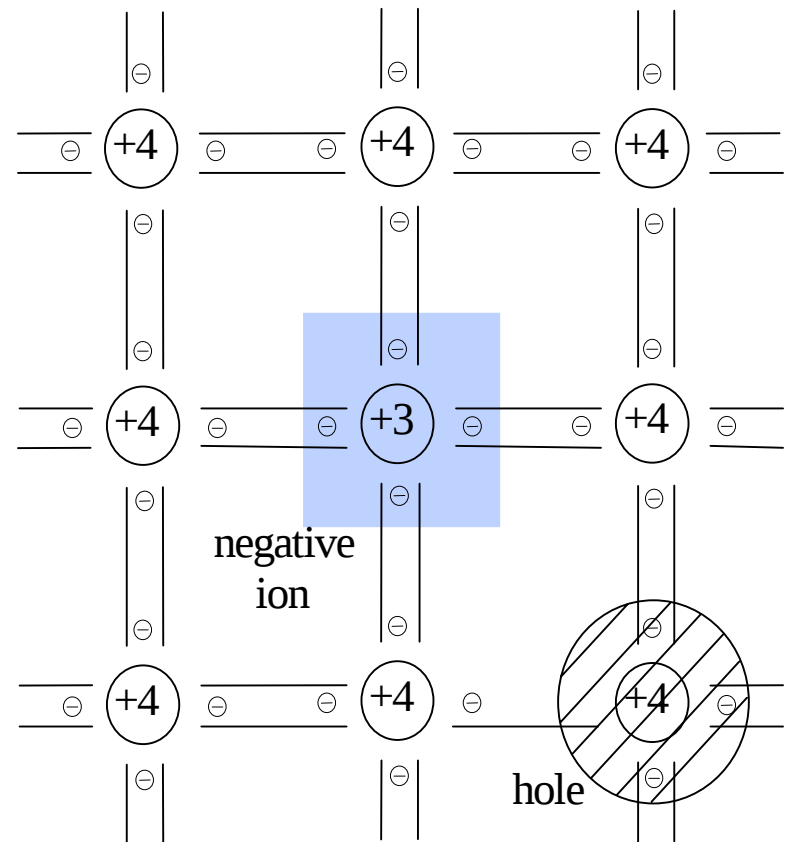
Semicondutor extrínseco

III			IV			V		
⊖ ⊖ (+3) ⊖			⊖ ⊖ (+4) ⊖			⊖ ⊖ (+5) ⊖		
5	B		6	C		7	N	
Boron 10.82			Carbon 12.01			Nitrogen 14.008		
13	Al		14	Si		15	P	
Aluminum 26.97			Silicon 28.09			Phosphorus 31.02		
31	Ga		32	Ge		33	As	
Gallium 69.72			Germanium 72.60			Arsenic 74.91		
49	In		50	Sn		51	Sb	
Indium 114.8			Tin 118.7			Antimony 121.8		

Semicondutor extrínseco (cont.)



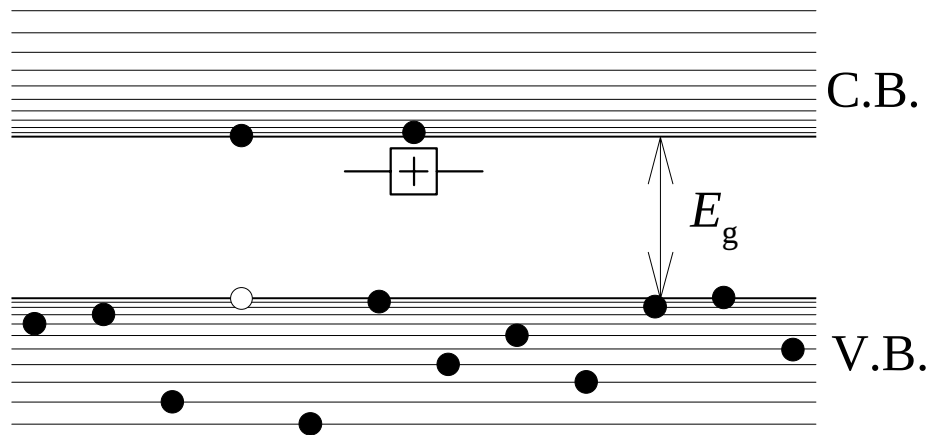
N-type doping



P-type doping

Semicondutor extrínseco (cont.)

(a) N-type doping



(b) P-type doping

