Lecture 1 Semiconductor Physics "Review"

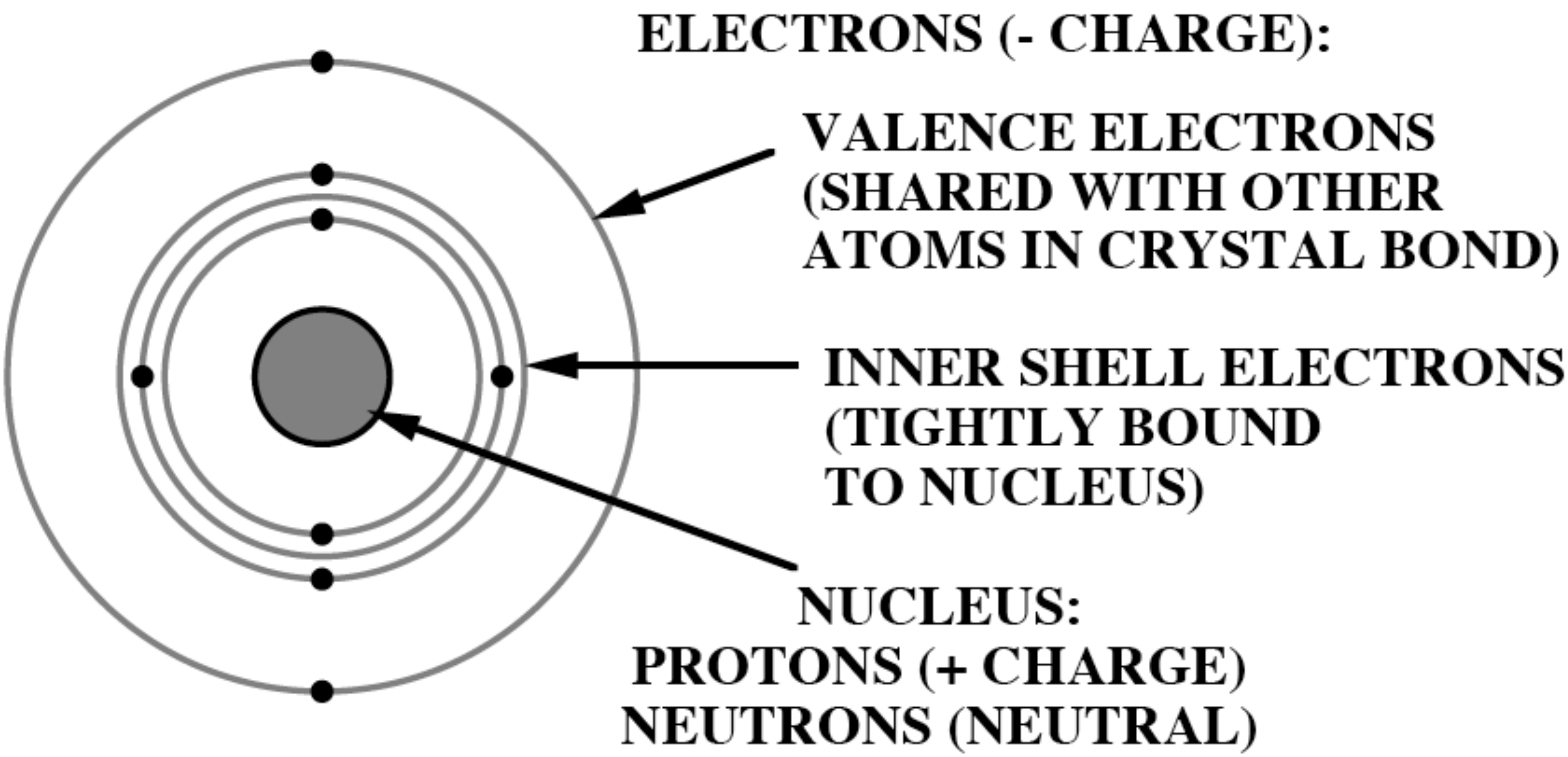
- **P-N Junction Diode**
  - **Reverse bias diode junction capacitance**
- **Text: Johns & Martin Sec. 1.1 pp. 1-12**

Semiconductor Physics “Review”

- Chemistry Review
- Types of Materials
  - Conductor, Insulator, Semiconductor
- PN junction
  - Depletion region
  - Junction capacitance

Chemistry Review

- **Model of atom (ridiculously oversimplified)**



Conduction

- Conductor
  - Each atom:valence e- not used in bond
  - "Sea of electrons"
  - Small applied V $\Rightarrow$ Lots of charge moving $\Rightarrow$ Large I $\Rightarrow$ Low resistance
- Insulator
  - All valence e- tightly bound
  - Applied V $\Rightarrow$ Little charge moving $\Rightarrow$ Small I $\Rightarrow$ High resistance
- Semiconductor
  - "In between"

Periodic Table

METALS

NONMETALS

TRANSITION METALS

PERIODS	I A	II A	III B	IV B	V B	VI B	VII B	VIII	VIII	VIII	I B	II B	III A	IV A	V A	VI A	VII A	0
1 0	1.0079 H [1] 1																1.0079 H [1] 1	4.00260 He [2] 2
2 2	6.941 Li [3] 1	9.01218 Be [4] 2											10.81 B [5] 3	12.011 C [6] 4	14.0067 N [7] 5	15.9994 O [8] 6	18.9984 F [9] 7	20.179 Ne [10] 8
3 2, 8	22.9898 Na [11] 1	24.305 Mg [12] 2											26.9815 Al [13] 3	28.086 Si [14] 4	30.9738 P [15] 5	32.06 S [16] 6	35.453 Cl [17] 7	39.948 Ar [18] 8
4 2, 8	39.098 K [19] 8, 1	40.08 Ca [20] 8, 2	44.9559 Sc [21] 9, 2	47.90 Ti [22] 10, 2	50.9414 V [23] 11, 2	51.996 Cr [24] 13, 1	54.9380 Mn [25] 13, 2	55.847 Fe [26] 14, 2	58.9332 Co [27] 15, 2	58.71 Ni [28] 16, 2	63.546 Cu [29] 18, 1	65.38 Zn [30] 18, 2	69.72 Ga [31] 18, 3	72.59 Ge [32] 18, 4	74.9216 As [33] 18, 5	78.96 Se [34] 18, 6	79.904 Br [35] 18, 7	83.80 Kr [36] 18, 8
5 2, 8, 18	85.4678 Rb [37] 8, 1	87.62 Sr [38] 8, 2	88.9059 Y [39] 9, 2	91.22 Zr [40] 10, 2	92.9064 Nb [41] 12, 1	95.94 Mo [42] 13, 1	98.9062 Tc [43] 14, 1	101.07 Ru [44] 15, 1	102.9055 Rh [45] 16, 1	106.4 Pd [46] 18	107.868 Ag [47] 18, 1	112.40 Cd [48] 18, 2	114.82 In [49] 18, 3	118.69 Sn [50] 18, 4	121.75 Sb [51] 18, 5	127.60 Te [52] 18, 6	126.9045 I [53] 18, 7	131.30 Xe [54] 18, 8
6 2, 8, 18	132.9054 Cs [55] 18, 8, 1	137.34 Ba [56] 18, 8, 2	[57-71] *	178.49 Hf [72] 32, 10, 2	180.9479 Ta [73] 32, 11, 2	183.85 W [74] 32, 12, 2	186.2 Re [75] 32, 13, 2	190.2 Os [76] 32, 14, 2	192.22 Ir [77] 32, 15, 2	195.09 Pt [78] 32, 17, 1	196.9665 Au [79] 32, 18, 1	200.59 Hg [80] 32, 18, 2	204.37 Tl [81] 32, 18, 3	207.2 Pb [82] 32, 18, 4	208.9804 Bi [83] 32, 18, 5	(210) Po [84] 32, 18, 6	(210) At [85] 32, 18, 7	(222) Rn [86] 32, 18, 8
7 2,8,18,32	(223) Fr [87] 18, 8, 1	226.0254 Ra [88] 18, 8, 2	[89-103] †	[104] 32, 10, 2	[105] 32, 11, 2	[106]	[107]	[108]										

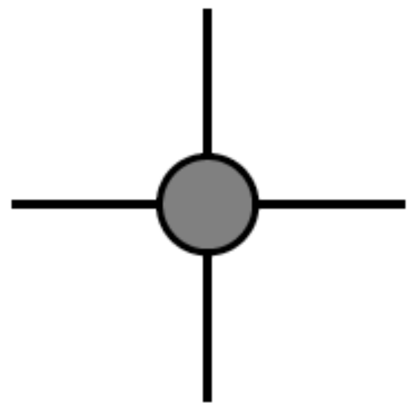
* LANTHANIDE SERIES	138.9055 La [57] 18, 9, 2	140.12 Ce [58] 20, 8, 2	140.9077 Pr [59] 21, 8, 2	144.24 Nd [60] 22, 8, 2	(145) Pm [61] 23, 8, 2	150.4 Sm [62] 24, 8, 2	151.96 Eu [63] 25, 8, 2	157.25 Gd [64] 25, 9, 2	158.9254 Tb [65] 27, 8, 2	162.50 Dy [66] 28, 8, 2	164.9304 Ho [67] 29, 8, 2	167.26 Er [68] 30, 8, 2	168.9342 Tm [69] 31, 8, 2	173.04 Yb [70] 32, 8, 2	174.97 Lu [71] 32, 9, 2
† ACTINIDE SERIES	(227) Ac [89] 18, 9, 2	232.0381 Th [90] 18, 10, 2	231.0359 Pa [91] 20, 9, 2	238.029 U [92] 21, 9, 2	237.0482 Np [93] 23, 8, 2	(242) Pu [94] 24, 8, 2	(243) Am [95] 25, 8, 2	(245) Cm [96] 25, 9, 2	(245) Bk [97] 26, 9, 2	(248) Cf [98] 28, 8, 2	(253) Es [99] 29, 8, 2	(254) Fm [100] 30, 8, 2	(256) Md [101] 31, 8, 2	(253) No [102] 32, 8, 2	(257) Lr [103] 32, 9, 2

Source: General Chemistry, ISBN 0-669-63362-3

Bonding model

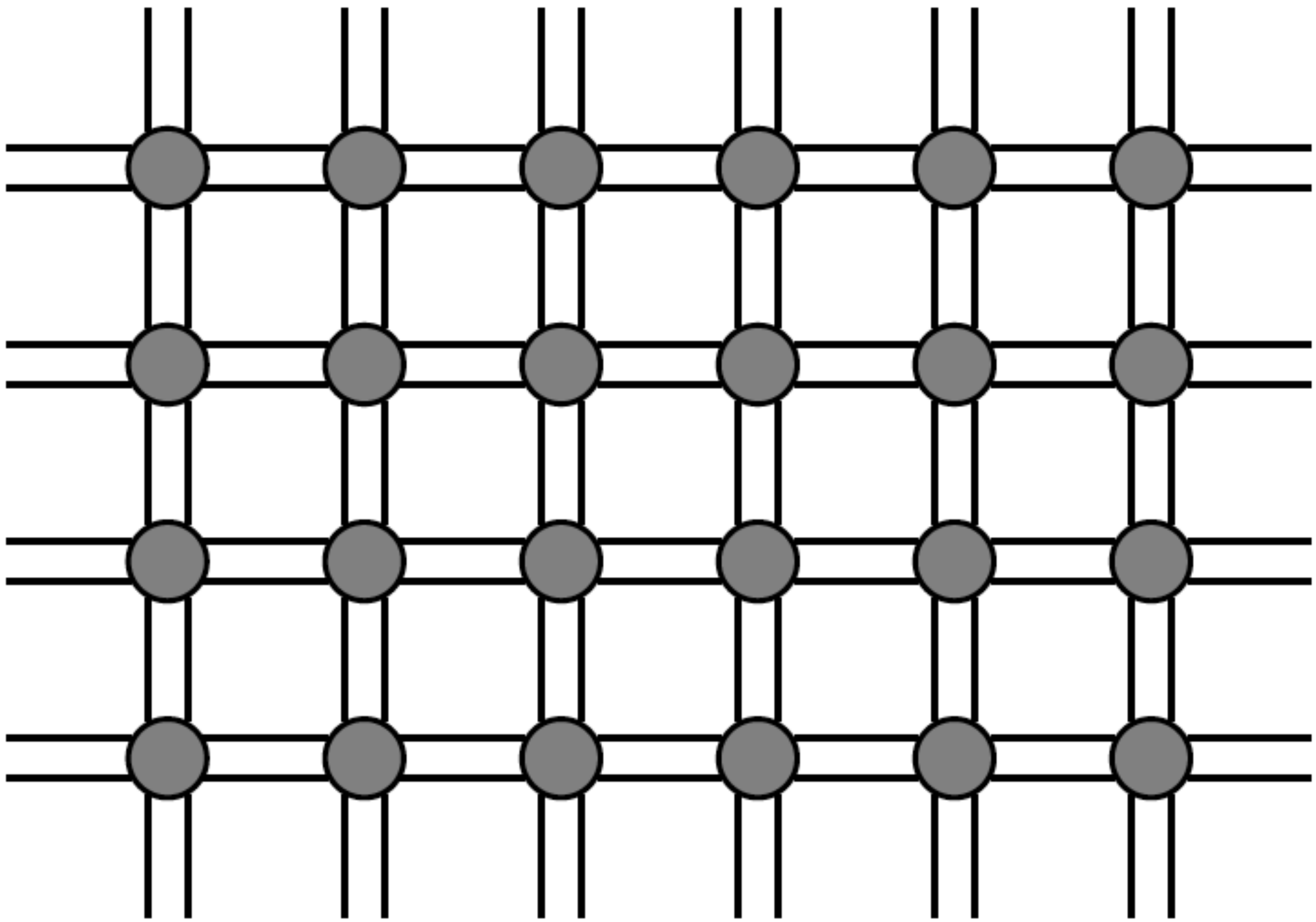
- **Lines represent valence electrons**
- **Silicon**

  4 valence electrons



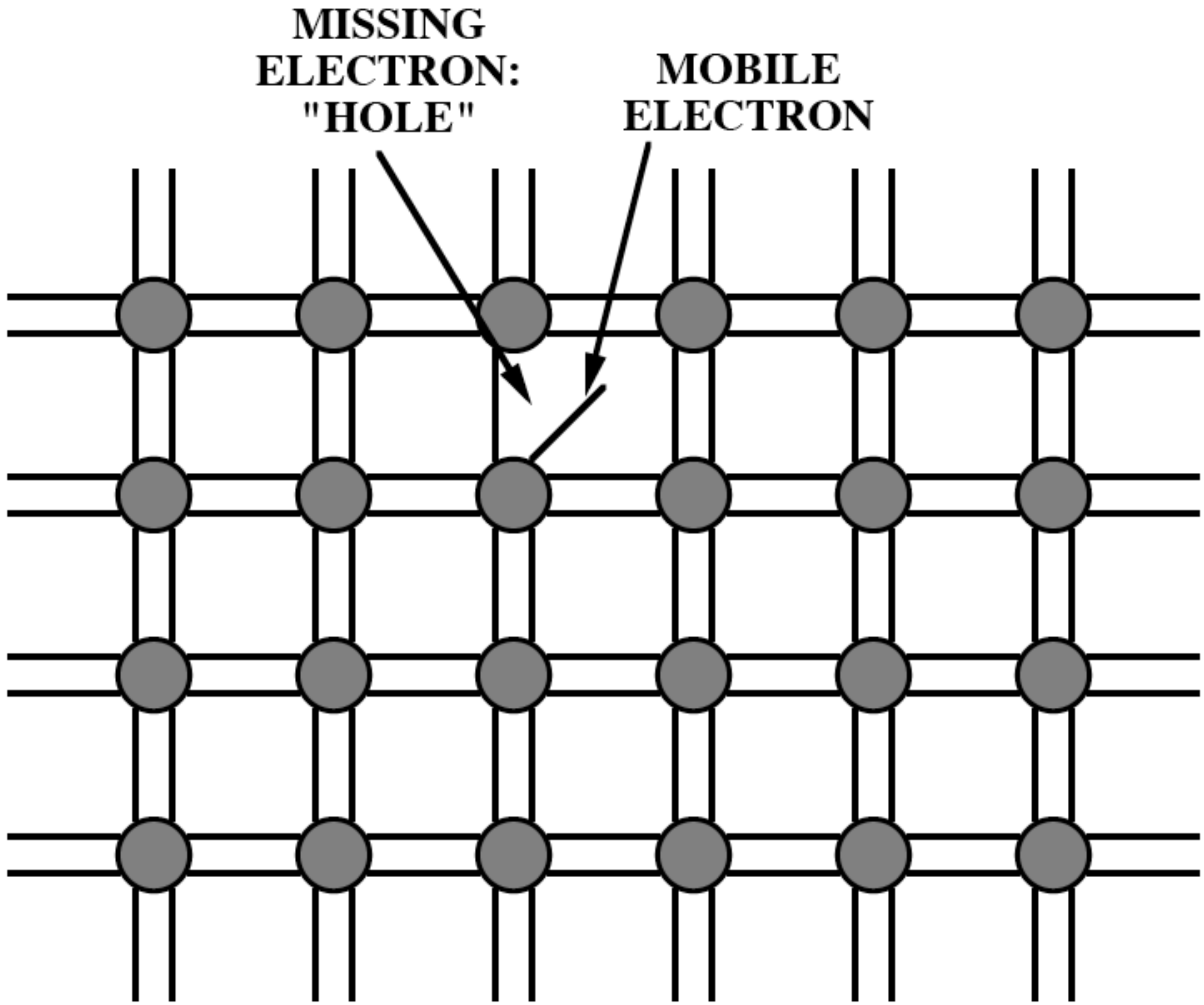
Pure (Intrinsic) Silicon, T = 0 °K (Absolute Zero)

All valence electrons tightly bound



Pure Silicon, T = 300 °K (Room Temperature)

Thermal energy frees some valence electrons



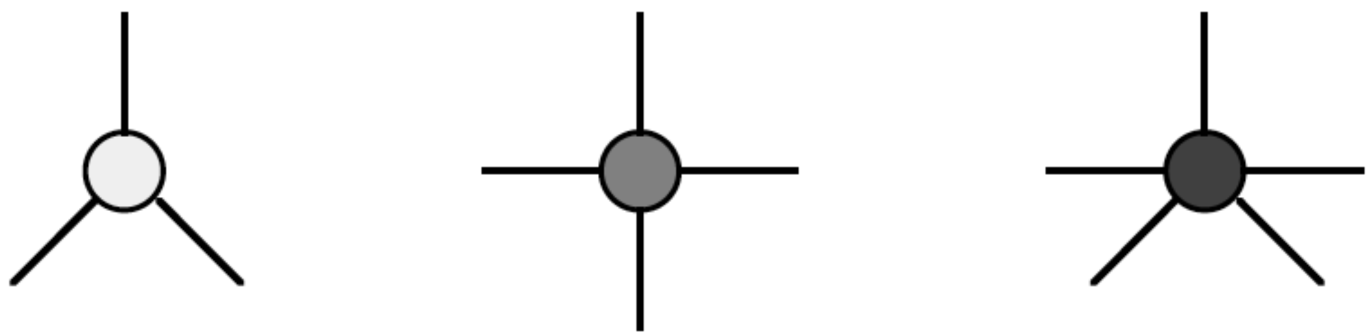
Pure Silicon, T = 300 °K (Room Temperature)

- Thermal energy frees some valence electrons
  - "electron": mobile negative charge
  - Missing electrons ("holes") behaves as mobile positive charge
- Equal number of holes, electrons
- Relatively poor conductor

Doping

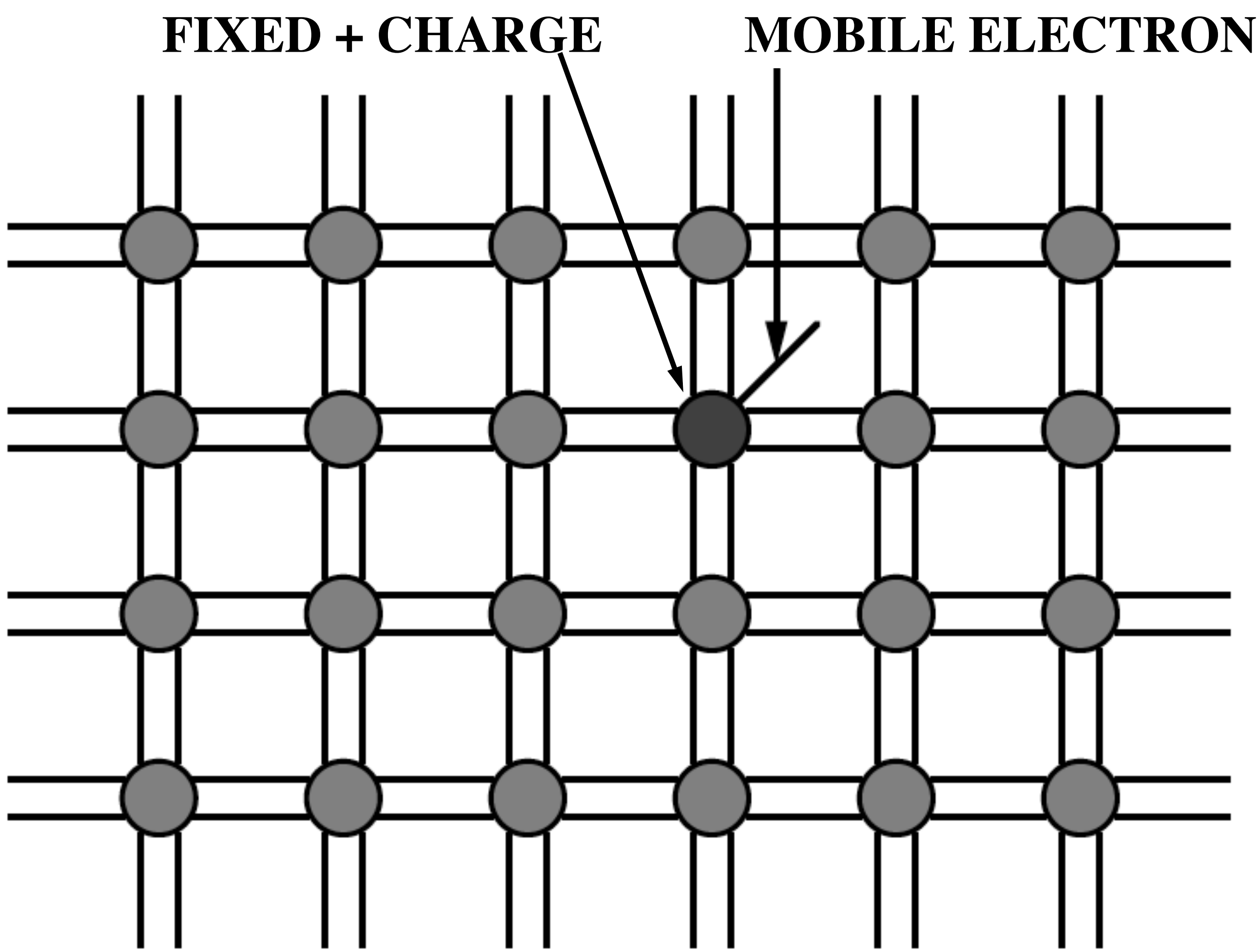
- **Intentionally introduce impurity atoms to unbalance number of holes, electrons**
- **Adjacent columns in periodic table**

Boron **Silicon** **Phosphorous**



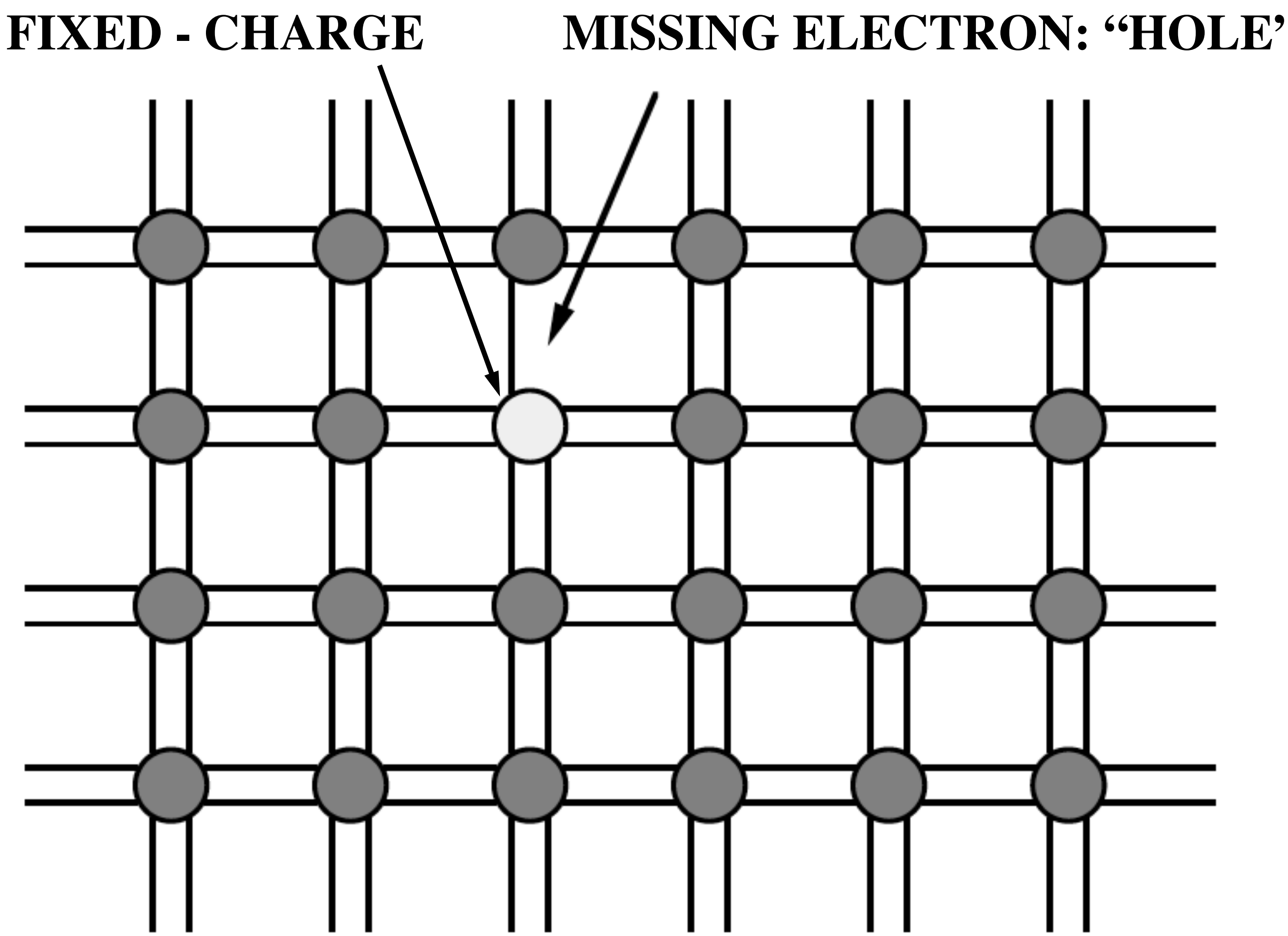
Donor: Phosphorous

- **Donates extra electron: mobile**
- **Also extra proton: Fixed +positive charge**
- **More mobile negative charges: n-type**



Acceptor: Boron

- **Vacancy ("hole") that can accept an electron**
- **Also missing proton: Fixed negative charge**
- **More mobile positive charges: p-type**



Caution

- **Entire semiconductor is electrically neutral**
- **Donor: extra proton in nucleus**
- **Acceptor: missing proton in nucleus**

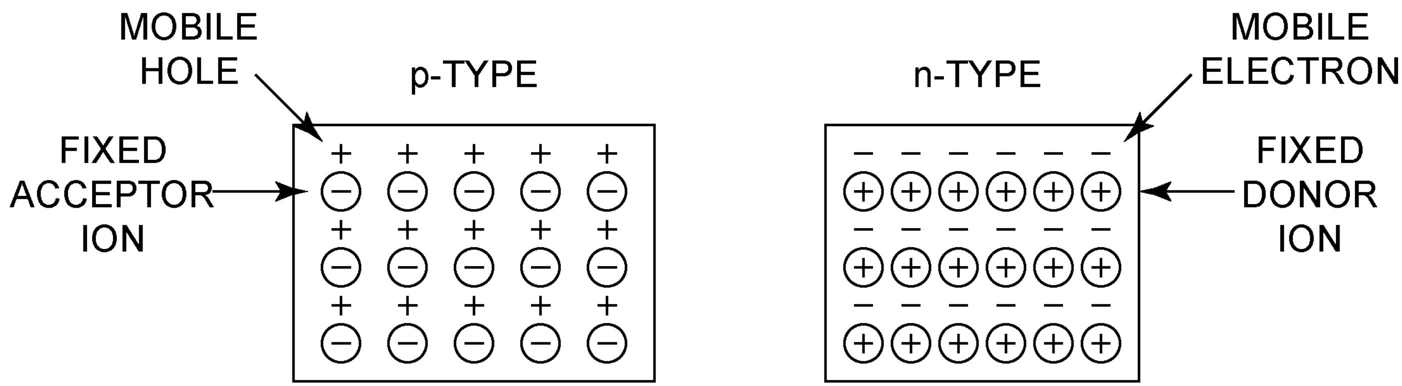
(for both, <u>relative to Si</u>)

P-N Junction Diode

- **Junction between p-type, n-type materials**
- **Assume structure is simple enough that we can consider only one spatial dimension**
- **Model: only consider "extra" charges**
- **Mobile charges contributed by dopants: each mobile charge was contributed by a fixed charge of opposite sign**

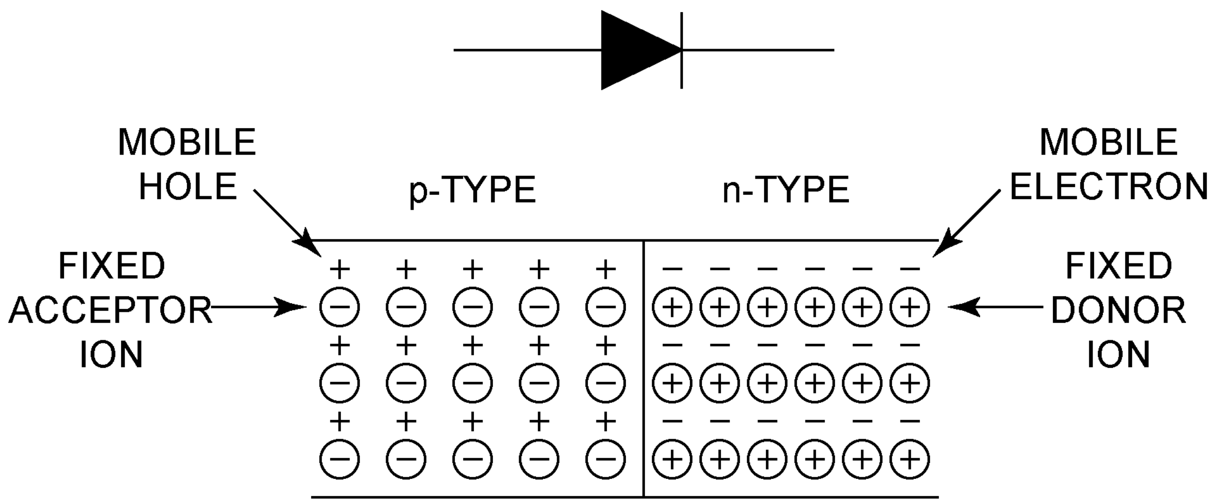
P-N Junction Diode

- **Thought experiment: take isolated p-type, n-type and bring together**



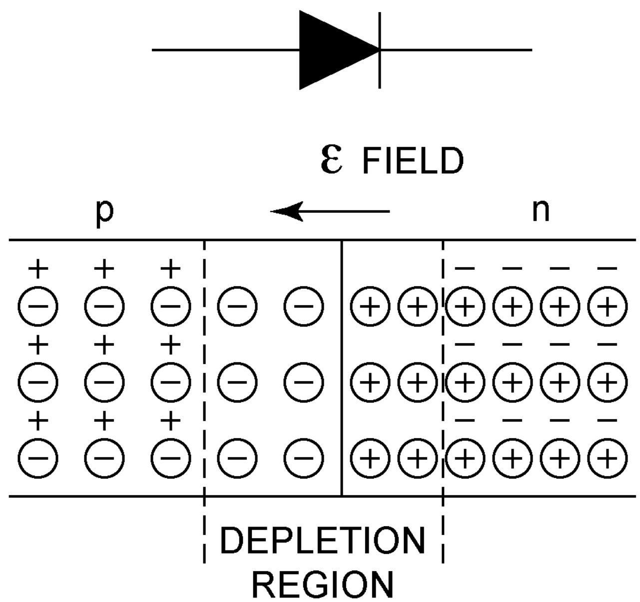
$V_A = 0$ (t=0)

- **No electric field; Thermal diffusion**



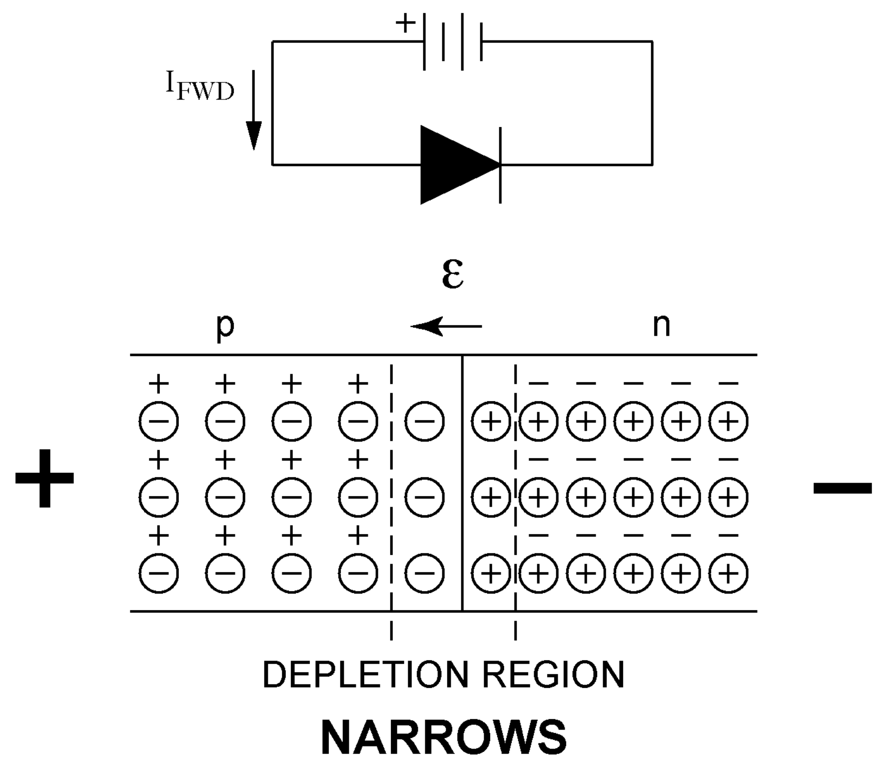
$V_A = 0$ (equilibrium $t > 0$)

- **Internal electric field balances diffusion**



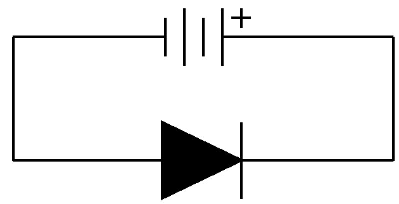
V_A positive (forward bias)

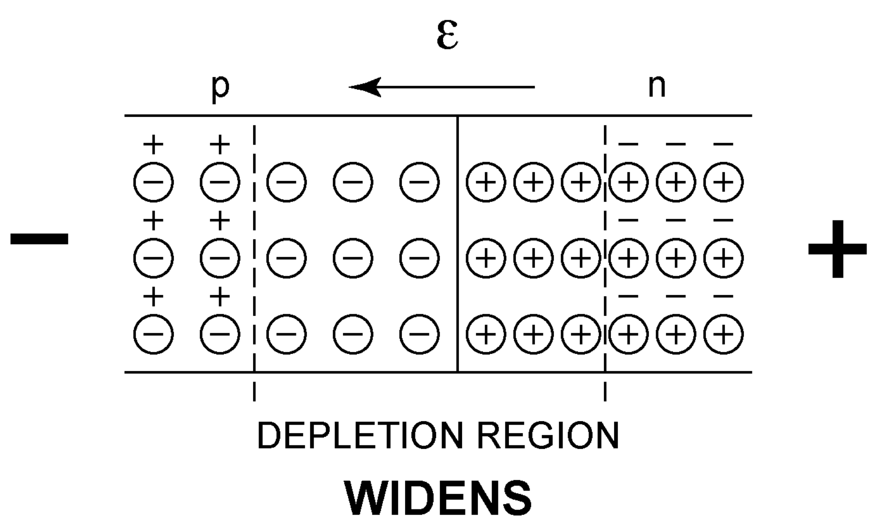
- **Applied V_A "overpowers" internal E field**



V_A negative (reverse bias)

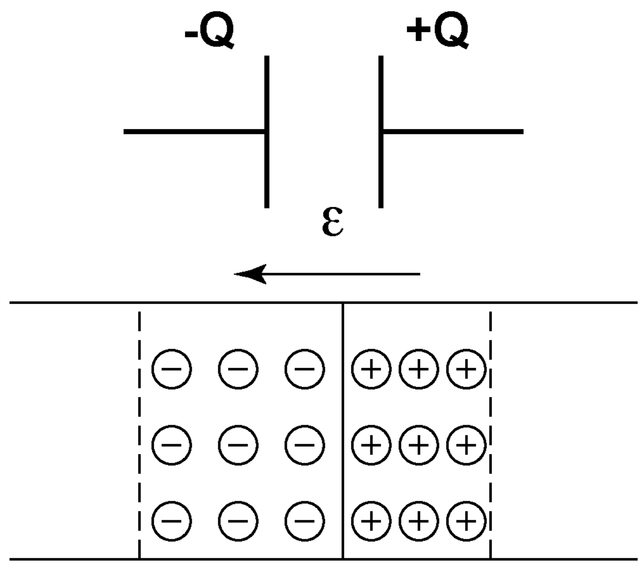
- Applied V_A "reinforces" internal E field
- Field "pulls" mobile charges further apart





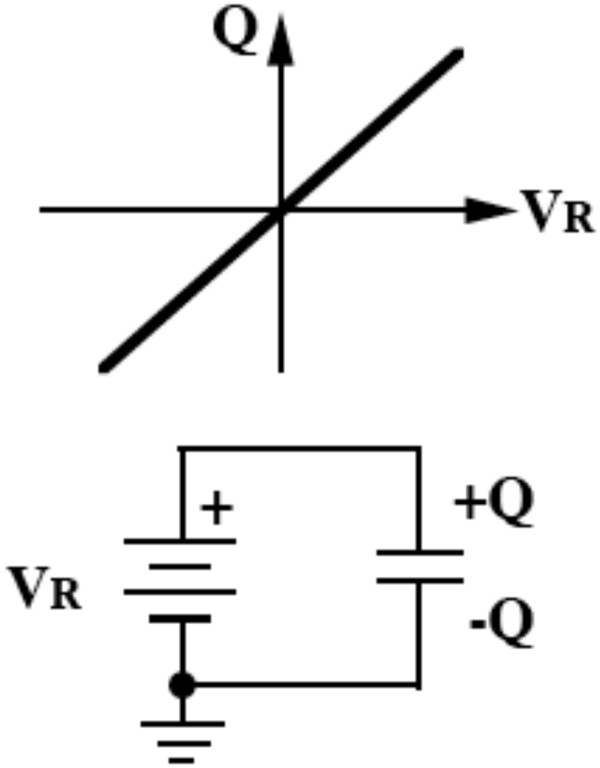
Junction Capacitance

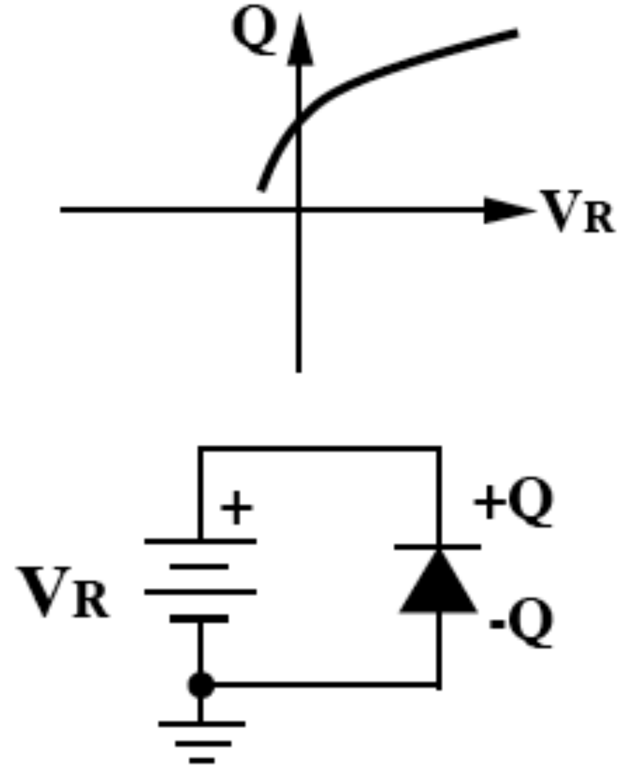
- **Equal and opposite charges, physically separated, changes with voltage: Capacitance!**



Junction Capacitance

C = dQ/dV





Same slope for any V

Linear capacitance

Slope depends on V

<u>Nonlinear capacitance</u>

Semiconductor Physics Review Summary

- **Conduction in semiconductor:**
  e- and "holes"(absence of electrons)
- **N region has mostly mobile electrons;**
  P region has mostly mobile "holes"
- **PN junction has a depletion region**
  (no mobile carriers)
- **Size of the depletion region depends on the applied voltage and the P, N doping**
- **Reverse biased PN junction acts like a nonlinear capacitor**