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)

  ELECTRONS (- CHARGE):

  VALENCE ELECTRONS (SHARED WITH OTHER ATOMS IN CRYSTAL BOND)

  INNER SHELL ELECTRONS (TIGHTLY BOUND TO NUCLEUS)

  NUCLEUS:
  PROTONS (+ CHARGE)
  NEUTRONS (NEUTRAL)
Conduction

- **Conductor**
  - Each atom: valence e- not used in bond
  - “Sea of electrons”
  - Small applied V ⇒ Lots of charge moving ⇒ Large I ⇒ Low resistance

- **Insulator**
  - All valence e- tightly bound
  - Applied V ⇒ Little charge moving ⇒ Small I ⇒ High resistance

- **Semiconductor**
  - “In between”
### Periodic Table

**METALS**

<table>
<thead>
<tr>
<th>Period</th>
<th>Group</th>
<th>Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>IA</td>
<td>H(1)</td>
</tr>
<tr>
<td>2</td>
<td>IIA</td>
<td>Li(3), Be(4)</td>
</tr>
<tr>
<td>3</td>
<td>IIIA</td>
<td>Na(11), Mg(12)</td>
</tr>
<tr>
<td>4</td>
<td>IVA</td>
<td>K(19), Ca(20)</td>
</tr>
<tr>
<td>5</td>
<td>Va</td>
<td>Rb(37), Sr(38)</td>
</tr>
<tr>
<td>6</td>
<td>VIA</td>
<td>Cs(55), Ba(56)</td>
</tr>
<tr>
<td>7</td>
<td>VIIA</td>
<td>Fr(77), Ra(88)</td>
</tr>
</tbody>
</table>

**TRANSITION METALS**

<table>
<thead>
<tr>
<th>Period</th>
<th>Group</th>
<th>Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>IB</td>
<td>V, VIIB, VIIB, VIIIB, VIII</td>
</tr>
<tr>
<td>3</td>
<td>IIB</td>
<td>Sc(21), Ti(22), V(23), Cr(24), Mn(25), Fe(26), Co(27), Ni(28), Zn(29)</td>
</tr>
<tr>
<td>4</td>
<td>IIIA</td>
<td>Nb(41), Mo(42), Tc(43), Ru(44), Rh(45), Pd(46), Ag(47), Cd(48)</td>
</tr>
<tr>
<td>5</td>
<td>IVB</td>
<td>Ta(71)</td>
</tr>
</tbody>
</table>

**NONMETALS**

<table>
<thead>
<tr>
<th>Period</th>
<th>Group</th>
<th>Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>VIIA</td>
<td>Al(13), Si(14), P(15), S(16), Cl(17), Ar(18)</td>
</tr>
<tr>
<td>3</td>
<td>VIA</td>
<td>K(39), Ca(40), Sc(41), Ti(42), V(43), Cr(44), Mn(45), Fe(46), Co(47), Ni(48), Zn(49)</td>
</tr>
<tr>
<td>4</td>
<td>VII</td>
<td>Rb(57), Sr(58), Y(38), Zr(40), Nb(41), Mo(42), Tc(43), Ru(44), Rh(45), Pd(46), Ag(47), Cd(48)</td>
</tr>
<tr>
<td>5</td>
<td>VIII</td>
<td>Cs(55), Ba(56), Hf(72), Ta(71), W(74), Re(75), Os(76), Ir(77), Pt(78), Au(79)</td>
</tr>
<tr>
<td>6</td>
<td>IXA</td>
<td>Th(89), Pa(90), U(92), Np(93), Pu(94), Am(95), Cm(96), Bk(97), Cf(98), Es(99)</td>
</tr>
<tr>
<td>7</td>
<td>IXB</td>
<td>Ac(153), Th(88), Pa(90), U(92), Np(93), Pu(94), Am(95), Cm(96), Bk(97), Cf(98), Es(99)</td>
</tr>
</tbody>
</table>

**LANTHANIDE SERIES**

<table>
<thead>
<tr>
<th>Period</th>
<th>Group</th>
<th>Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-12</td>
<td>IIIA</td>
<td>La(37), Ce(35), Pr(39), Nd(60), Sm(58), Eu(63), Gd(64), Tb(59), Dy(65), Ho(67)</td>
</tr>
<tr>
<td>13-15</td>
<td>IIIB</td>
<td>Er(158), Tm(159), Yb(70), Lu(71)</td>
</tr>
</tbody>
</table>

**ACTINIDE SERIES**

<table>
<thead>
<tr>
<th>Period</th>
<th>Group</th>
<th>Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-12</td>
<td>IIIA</td>
<td>Ac(58), Th(23), Pa(21), U(92), Np(92), Pu(24), Am(95), Cm(96), Bk(97), Cf(98), Es(99)</td>
</tr>
<tr>
<td>13-15</td>
<td>IIIB</td>
<td>Cm(25), Bk(25), Cf(25), Es(25), Fm(25), Md(25)</td>
</tr>
</tbody>
</table>

Bonding model

- Lines represent valence electrons
- Silicon
  - 4 valence electrons
Pure (Intrinsic) Silicon, $T = 0 \, ^\circ K$ (Absolute Zero)

All valence electrons tightly bound
Pure Silicon, $T = 300 \, ^\circ\text{K}$ (Room Temperature)

Thermal energy frees some valence electrons

MISSING ELECTRON: "HOLE"

MOBILE ELECTRON
Pure Silicon, $T = 300 \, ^\circ\text{K}$ (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, relative to Si)
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!

![Diagram showing junction capacitance with equal and opposite charges separated by a medium with dielectric constant ε.](image-url)
Junction Capacitance

\[ C = \frac{dQ}{dV} \]

Same slope for any \( V \)
Linear capacitance

Slope depends on \( V \)
Nonlinear capacitance
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