Lec 15: Intro to Semiconductor circuits

Last time: more practice w/ linear circuits

Today:
- Power dissipated in resistor
- Semiconductors and nonlinear circuit intro

Diode
Power dissipated in a resistor

Resistance $\Delta t = \text{time between collisions}$

$\Rightarrow$ collisions transfer energy from charge to lattice

$\Rightarrow$ potential energy of charge drops in resistor

$\Rightarrow$ voltage drop as current moves through resistor

Since energy is conserved, we can compute the energy being dissipated.

\[ \Delta (\text{potential energy}) = -(\Delta E_{\text{diss}}) \]

\[ \Delta (\text{potential energy}) = -(\text{charge})(\text{potential drop per charge}) \]

\[ = - (I \Delta t)(IR) \]

\[ \therefore \frac{\Delta E_{\text{diss}}}{\Delta t} = \text{Power dissipated} \equiv P = I^2R \]
conductors: Previously, talked about classical intuition. Here, contrast info to semiconductors
copper

- charge carriers are \(e^-\)
- electrons behave as fluid "waves" seeing many lattice ions together.
- these electrons are delocalized: not bound to any particular lattice ion
- there are many momentum states accessible ("free fluid w/ unobstructed movement")
- more understanding after quantum, stat mech, and solid state
Semi conductor:
e.g. SI (Atomic # 14)  

covalent bonds that have localized electron sharing  

At room temperature, it is a poor conductor  

Add impurities to have delocalized charge carriers (about 1 part in $10^6$):

- Add phosphorous $\rightarrow$ loosely bound $e^-$ $\rightarrow$ donates delocalized $e^-$
  $= n$-type semiconductor

- Add aluminum $\rightarrow$ sucks in $e^-$ $\rightarrow$ donates holes (absence of delocalized $e^-$)
  $= p$-type semiconductor
Effective "positive charge" (≡ hole) is "cancelling" the Al bond w/the silicon (another way to say Al is not bonding w/the silicon).

At room temperature, this hole can gain enough energy to propagate like a conduction charge.

Consider P-N junction:

\[ \text{P} \quad \text{N} \]

If \( \vec{E} \) field is from \( n \) to \( p \) direction,

\[ \text{P} \quad \text{N} \]

\[ \text{P} \quad \text{N} \]

\[ \text{P} \quad \text{N} \]

\[ \text{P} \quad \text{N} \]

\[ \text{P} \quad \text{N} \]

\[ \text{P} \quad \text{N} \]

\[ \Rightarrow \] No current can flow across the junction.
If $\vec{E}$ field is from p to n direction,

![Diagram](image)

The donor electron can fill the hole and current can flow freely.

![Diagram](image)

$I \approx I_s \left( e^{\frac{g V_D}{kT}} - 1 \right)$

$\frac{bT}{g} \approx 25 \times 10^{-3} V$

$g$ and $I_s$ are device dependent

Example of a nonlinear circuit element
Often idealizations are made to simplify design process:

e.g. To account for turn-on at $V = 0.6\, V$, 

$$
\begin{align*}
&\text{A} & \text{B} \\
&\approx & \\
& I & 0.6
\end{align*}$$
General procedure for diode circuits

1) Draw a subcircuit for each possible state of the diodes. For \( n \) diodes there are \( 2^n \) configurations.

2) Analyze each resulting circuit to find an expression for the desired output variable.

3) Find the validity range of each case

**Example**

\[
E = 5 \text{ V}
\]

\[
\begin{align*}
V_A & \quad \text{with} \\
V_B & \\
V_c & \quad \text{with} \\
\end{align*}
\]

Show that this is an AND gate if

<table>
<thead>
<tr>
<th>State</th>
<th>( V_A )</th>
<th>( V_B )</th>
<th>( V_c )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( 0 )</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>( 1 )</td>
<td>5V</td>
<td>5V</td>
<td>5V</td>
</tr>
</tbody>
</table>
1. \( V_c = 5\, V \quad V_A = V_B = 5\, V \quad 1 \& 1 = 1 \)

2. \( V_c = 0 \quad V_A = 0 \quad 0 \& 1 = 0 \)

3. \( V_c = 0 \quad V_A = 5\, V \quad 1 \& 0 = 0 \)

4. \( V_c = 0 \quad V_A = 0 = V_B \quad 0 \& 0 = 0 \)