Lecture 5 Diodes

Resistors, capacitors, inductors all <u>linear</u>

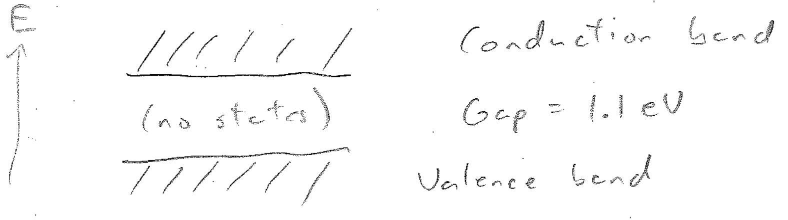
Current is linear fcn of voltage

Many important elements are nonlinear

Simplest: diode = semiconductor junction

Start by describing physics of silicon

Energy levels:



Valence band normally full of electrons

Conduction band empty

⇒ Si is an insulator (poor one, because gap is small)

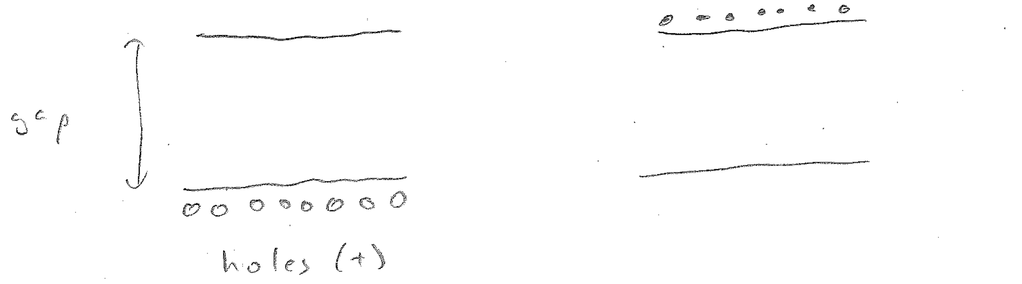
Interesting effects when doped with impurities

Two types: p: captures e^- from valence band, leaves hole

n: donates e^- to conduction band

Donated holes/electrons provide conduction

Picture:



Note, captured charges aren't shown. Total system is neutral charge

Diode = pn junction

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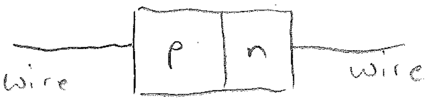
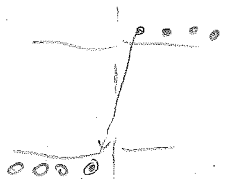


At junction, electrons from n-type fill holes in p-type

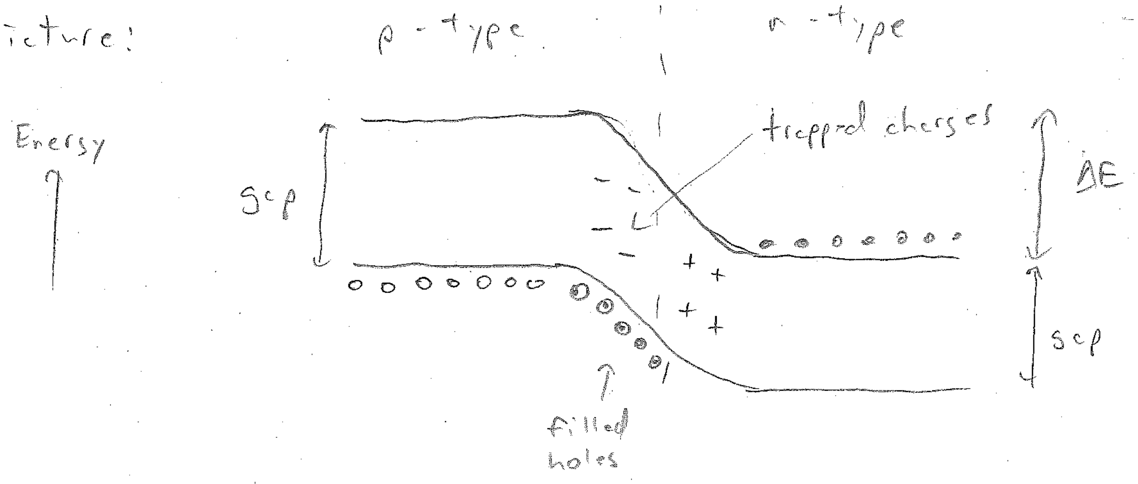


Leave captured charges behind, build up static charge

Resulting electric field keeps carriers near junction

Think about using electric potential

Total picture:



In junction area, no carriers: insulating layer

But two effects do allow current:

1) Thermal excitation in p-type: electrons excited from V to C

Then roll down hill into n-type

⇒ current from n to p

"thermal current"

2) Electrons in n-type might have enough thermal energy to overcome barrier, drift into p-type

Then recombine with holes

⇒ current from p to n

"recombination current"

In equilibrium, currents cancel $\Rightarrow I_{TOT} = 0$

Now, say we apply voltage V to junction

Changes barrier height $\Delta E \to \Delta E_0 - eV$

$I_{thermal} \propto e^{-E_{gap}/kT}$: doesn't change

$I_{recomb} \propto e^{-\Delta E/kT}$ does change

$$I_r \propto e^{-\frac{\Delta E_0}{kT} + \frac{eV}{kT}} = e^{-\frac{\Delta E_0}{kT}} e^{\frac{eV}{kT}}$$

$$I_r \equiv I_s e^{eV/kT}$$

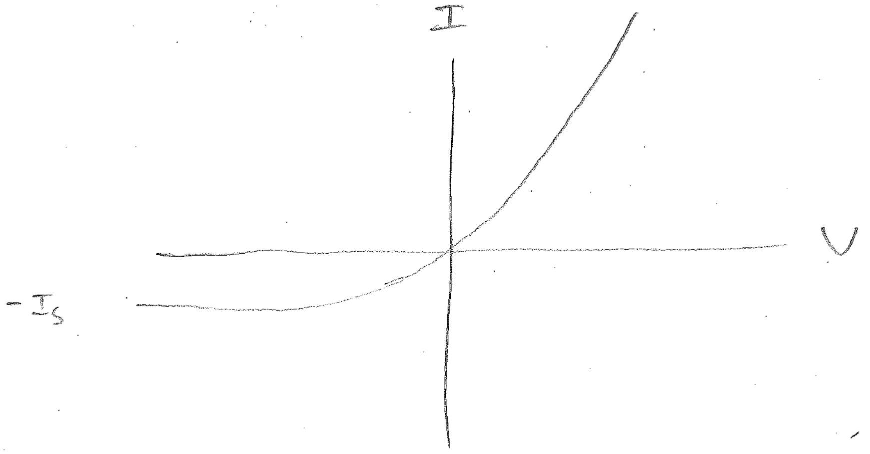
I_s = "scale current"

So $I_{TOT} = I_s e^{eV/kT} - I_{therm}$

At $V = 0$, know $I_{TOT} = 0 \Rightarrow I_{therm} = I_s$

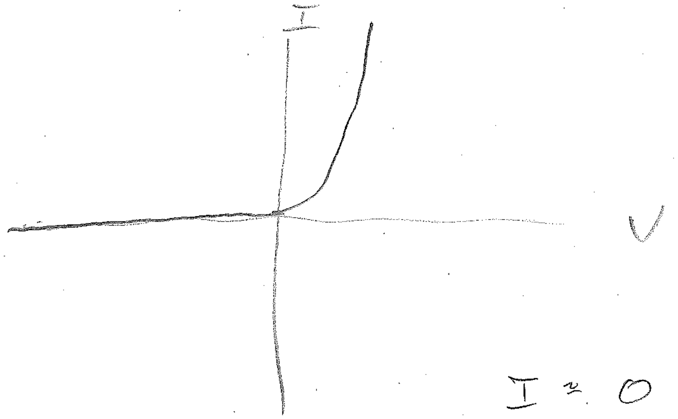
All together, $I_{TOT} = I_s(e^{eV/kT} - 1)$

Really $I = I_s(e^{V/V_0} - 1)$ $V_0 \approx \frac{kT}{e}$, varies by ~factor of 2



For typical diode, I_s is very small, ~ nA

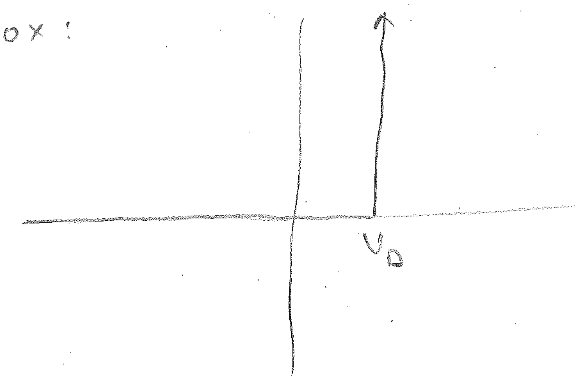
So on mA scale, looks like



$I \approx 0$ unless $V >$ few V_0

then I grows really fast

Simple approx:



Take $I = 0$ for $V < V_D$

$I = \infty$ for $V > V_D$

$\Rightarrow$ no current if $V < V_D$

Then V "clamped" at V_D

Call V_D = diode drop

typ. ~ 0.6V

Effect: think of diode as one-way valve

—▷|— : only current →

Takes small forward voltage V_D to "open" valve

Very nonlinear behavior, useful in many situations