Reference:C:\Users\Bernhard Boser\Documents\Files\Lib\MathCAD\Default\defaults.mcd

L03: pn Junctions, Diodes

Intrinsic Si

Q: What are n, p?
Q: Is the Si charged?
Q: How could we make n=1?
Q: Suppose n=1, p=0. Show charges as a function of time. [n moves, p stays]
Q: What is the characteristic difference between pos and neg charges in this example? [pos are fixed, neg can move].

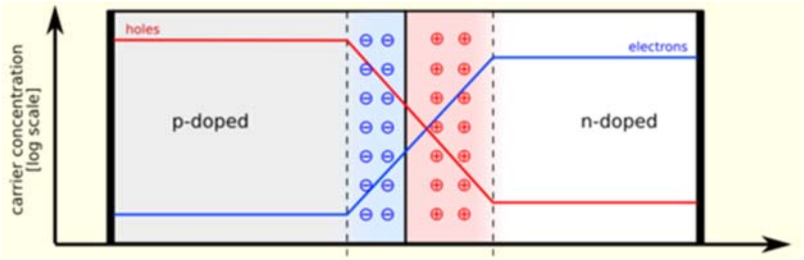
Doped Si

Q: Design Si with n=1000cm^3 at room temp. [p=N_A=1e17cm^-3, Boron]
Q: What happens to the "extra" n? [recombination]
Q: Is the Si charged? Show 1 acceptor (with 4 electrons), the and its hole (Si also) & count charges.
Q: What other way is there to reduce n? [lower temperature]

pn Junction

Place n, p adjacent to each other.

Q: Plot n, p far from junction.
Q: Is Si neutral (far from junction)?
Q: What happens to n, p near junction? [Diffusion]
Q: If you did this with water and orange juice, eventually you would get uniform densities. Will the same happen with n, p? [No, electrical field stops the process]
Q: Draw mobile charges (i.e. n, p) near junction. Is this region neutral? [no]
Q: What is the direction of E in junction? [n to p, impedes diffusion]
Q: In equilibrium, drift and diffusion for n and p (individually) concel each other. What carrier motion would we observe in a "charge microscope"? [random, can't see which charges move due to drift and diffusion, although could argue that all motion with field is drift, opposite is diffusion.]
Q: Explain why there is a potential drop (built-in voltage) in the junction. [field]
Q: Why won't the built-in voltage appear across the terminals of a real diode? [ohmic contacts]
Q: How could we get a voltage to appear across a diode without current flowing? [contacts at different temperature]



Reverse Bias

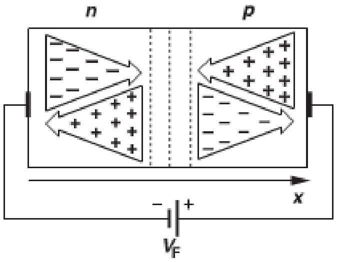
Apply voltage from n to p.

Q: What happens to E? [gets bigger]
Q: What happens to width of space charge region? [extends]
Q: Is current flowing? [No, the mobile carrier density in the junction is low -> no current.]
Q: What happens if an electron is injected into depletion region on n-side? [swept to n-side by E-field. Minority carriers do flow! Exploited in transistor]

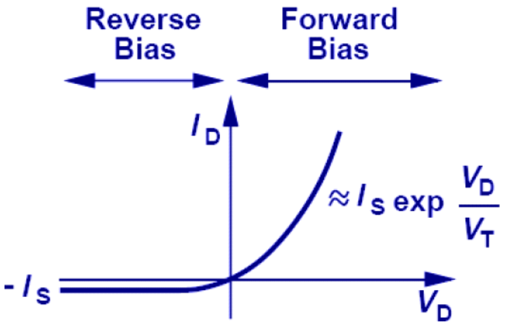
Forward Bias

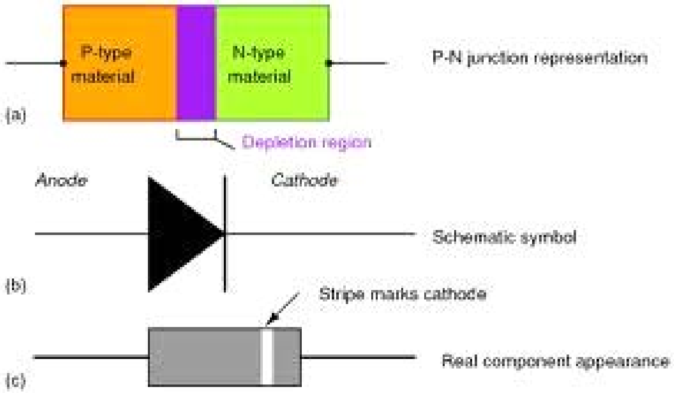
Apply voltage from p to n.

Q: What happens to E? [gets smaller]
Q: What happens to width of space charge region? [contracts]
Q: What happens to diffusion current? [Higher gradient, increases!]
Q: What happens to drift current? [Lower field, decreases!]
Q: Is net current flowing in junction? [Yes! Diffusion current dominates]
Q: What happens far from junction? [1) current must continue to flow 2) recombination "converts" minority carrier current to majority carrier curent]



Diode





$$V_T = V_t = \frac{k_B \cdot T}{q_e} \qquad \frac{k_B \cdot 300K}{q_e} = 25.853\,mV$$

Which T to use in design?
How to build "precise" electronics?
[E.g. feedback]

"Ideal diode" equation:

$$I_D = I_S\left(e^{V_D/V_T} - 1\right)$$

$$I_S = AJ_S = Aqn_i^2\left(\frac{D_n}{N_A L_n} + \frac{D_p}{N_D L_p}\right)$$

- Large current in forward direction
- Small current in reverse (due to recombination)

Diode Models

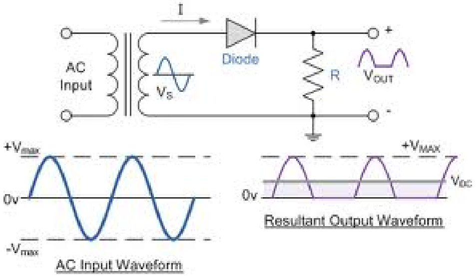
1. Full nonlinear model (actual diode equations are even more complicated)
2. Check-valve with turn-on voltage.
3. Ideal check-valve.
4. Other: e.g. small signal model (see later)

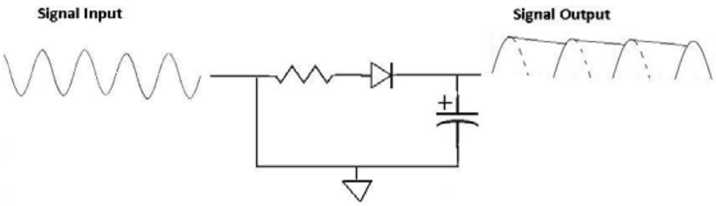
Physics of electronic devices is very complicated, accurately described by very complicated equations (often partial differential equation).
Key in design is to use the simplest model that gives the right answer.
As designer, you need to determine which model is appropriate (and check, e.g. with simulation, making sure the simulator uses a "sufficiently correct" model).

Is this easy? Experience helps, but no, not really easy.

Diode Applications

Power Supply





How choose C?

1. Complex equations.
2. Worst case design: little larger capacitor does not alter function, significantly increase cost and it adds margin --> safe design approach in this case

$I_{max} := 100mA$ max (not really constant, e.g. for varying or R-load)

$f_{60} := 60Hz$ $T_{60} := \frac{1}{f_{60}}$ $T_{60} = 16.667\,ms$

$\Delta V_{max} := 200mV$ $Q_{max} := I_{max} \cdot T_{60}$ $Q_{max} = 1.667\,mC$

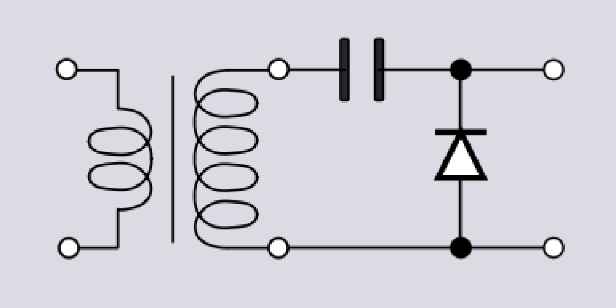
$C_{min} := \frac{Q_{max}}{\Delta V_{max}}$ $C_{min} = 8.333\,mF$

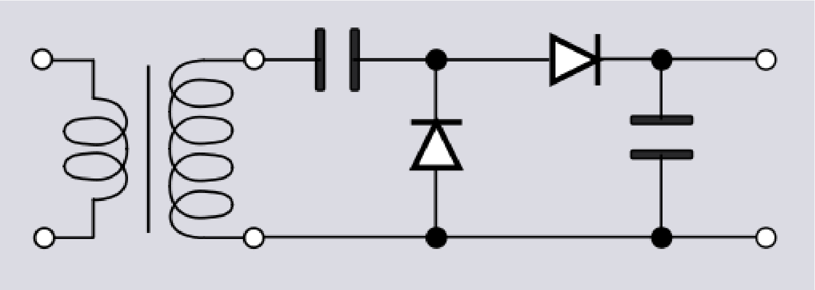
Is this a big cap? Yes, rather, but available. Rating for peak! How reduce?

- increase dVmax
- increase freq
- full-wave rectifier

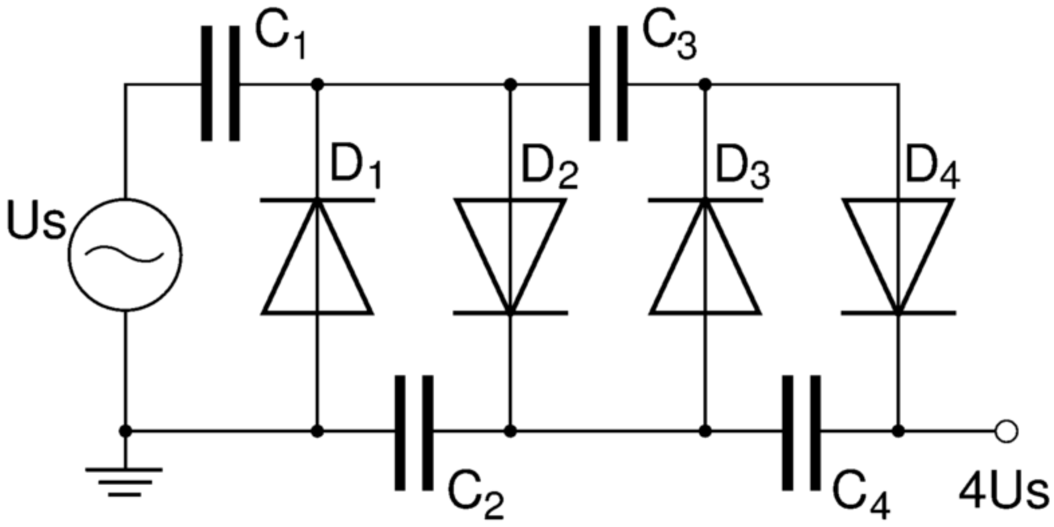
Voltage Multiplier

- Us is ac voltage
- Caps initially discharged
- Ideal diodes (zero threshold) -> understand operation first





Greinacher circuit


C1
C3
D1
D2
D3
D4
Us
C2
C4
4Us