EE 724: PN Junction L3

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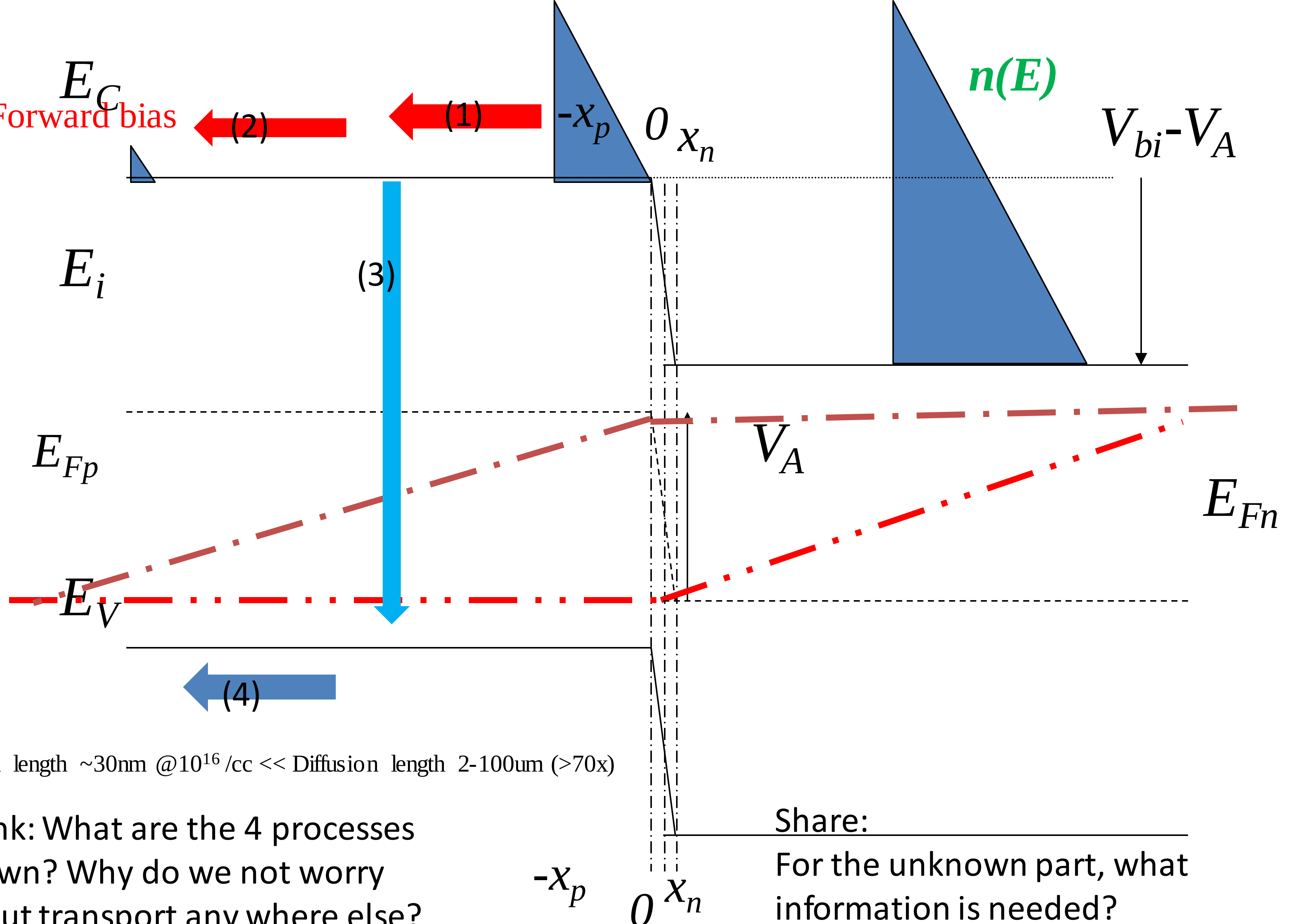
11/3/2019



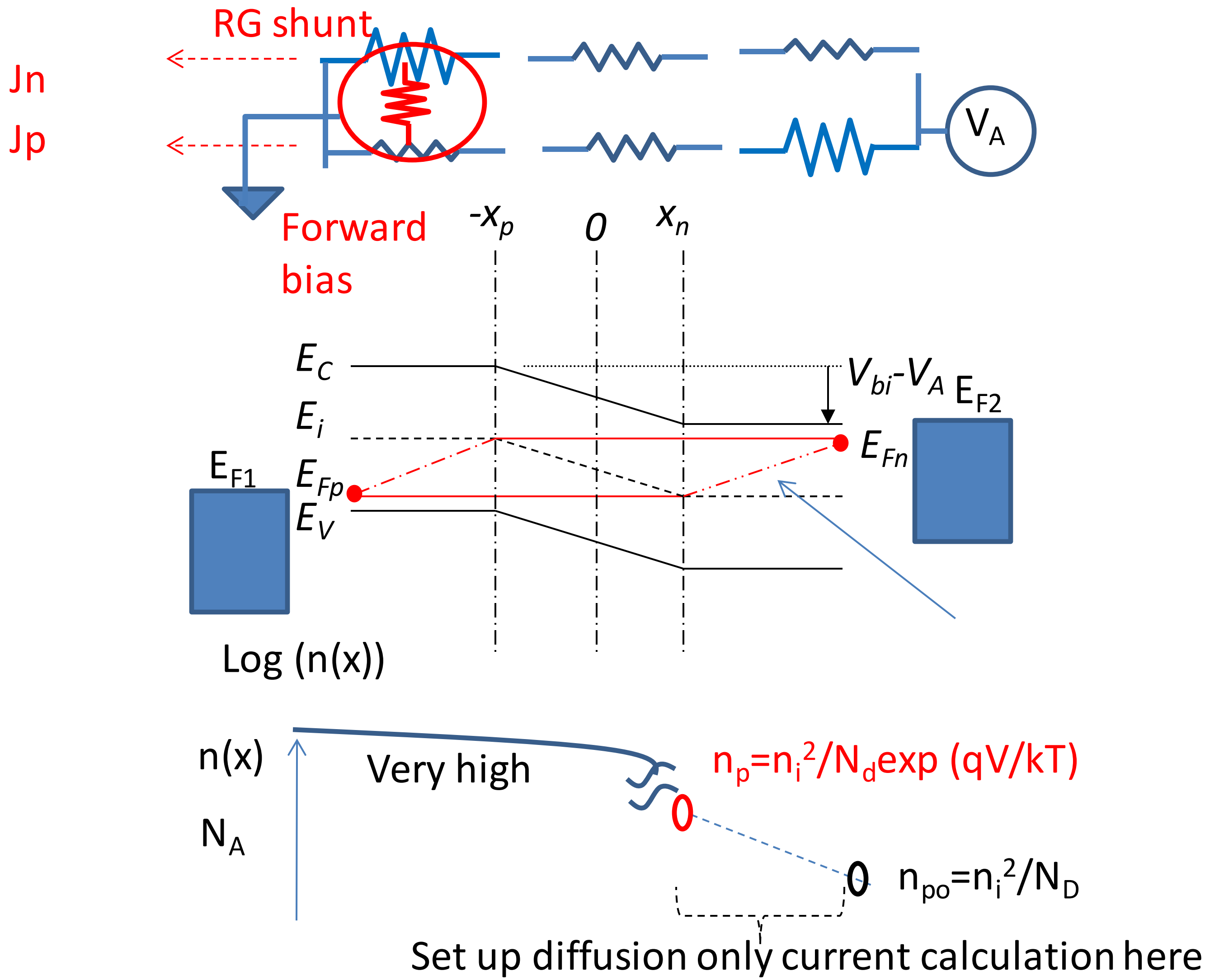
Depletion length ~30nm @10^{16} /cc << Diffusion length 2-100um (>70x)

Think: What are the 4 processes shown? Why do we not worry about transport any where else?

Share:
For the unknown part, what information is needed?
Can you tell which is fast from 1-4?
Write down continuity equation

Resistive network with recombination

Rather than traveling in minority carrier band (highly resistive); a shunt path to majority carrier band can be availed through recombination



Current calculation in the Base

$$\frac{dn}{dt} = \frac{1}{q}\frac{dJ_n}{dx} + R + G$$

$$J_n = qn\mu E + D\frac{dn}{dx}$$

$$\frac{dn}{dt} = q\mu\left(\frac{dn}{dx}E + n\frac{dE}{dx}\right) + D\frac{d^2n}{dx^2} + R + G$$

$$R - G\Big|_{thermalSRH} = -\frac{np - n_i^2}{\tau_p(n+n_1) + \tau_n(p+p_1)}$$

$$\frac{dn}{dt} = D\frac{d^2n}{dx^2} + \frac{n - n_o}{\tau}$$

τ is lifetime of electron

Using Steady State condition

$$\frac{dn}{dt} = D\frac{d^2n}{dx^2} + \frac{n - n_o}{\tau} = 0$$

Change in gradient

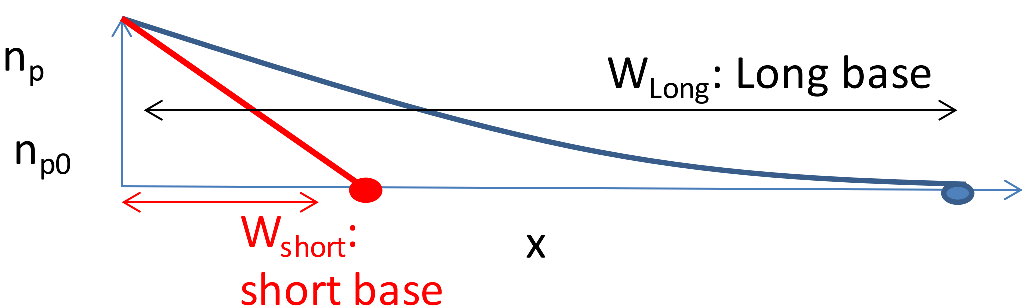
$$\frac{d^2n}{dx^2} + \frac{n - n_o}{D\tau} = 0$$

Loss from band

Diffusion length $L^2 = D\tau$

2 cases:

1. L<<W i.e. will recombine before reaching contacts
2. L<<W i.e. will reach contact without recombining significantly



Think: What is n_p?

Share:

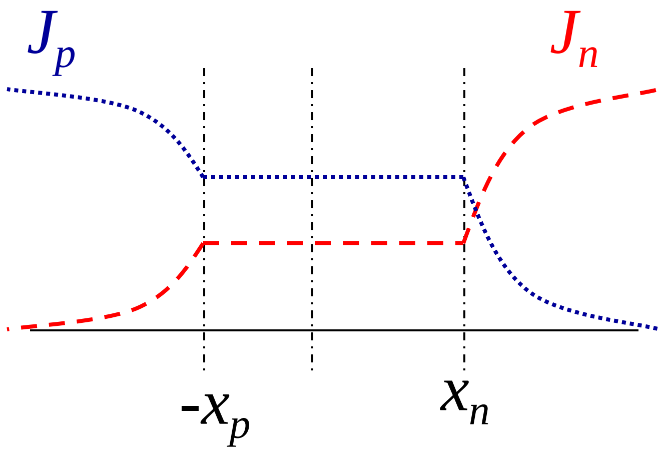
Calculate n (x)

Calculate the diode currents in two cases.

Long-Base Diode IV Characteristics

1. Ignore drift for minority current

$$D_p \frac{d^2 \Delta p_n}{dx'^2} - \frac{\Delta p_n}{\tau_n} = 0 \qquad x' \geq 0$$



2. Solve with the two boundary conditions

$$J_p(x') = q \frac{D_p}{L_p} \frac{n_i^2}{N_D} \left(e^{qV_A/kT} - 1\right) e^{-x'/L_p}$$

$$L_n = \sqrt{D_n \tau_n} \qquad L_p = \sqrt{D_p \tau_p}$$

3. Combine J_n and J_p at x_n or x_p

$$J = J_n(x = -x_p) + J_p(x = x_n) =$$

$$q\left(\frac{D_n}{L_n}\frac{n_i^2}{N_A} + \frac{D_p}{L_p}\frac{n_i^2}{N_D}\right)\left(e^{qV_A/kT} - 1\right)$$

$$I = A \cdot J = I_0\left(e^{qV_A/kT} - 1\right)$$

$$I_0 = qA\left(\frac{D_n}{L_n}\frac{n_i^2}{N_A} + \frac{D_p}{L_p}\frac{n_i^2}{N_D}\right)$$

Short-Base Diode IV

If we do not have "long" quasi-neutral region (in comparison with L_n or L_p), and Ohmic boundary condition is posed at $x=W_p$ and $x=W_n$ (notice the confusing notation here):

$$D_p \frac{d^2 \Delta p_n}{dx'^2} - \frac{\Delta p_n}{\tau_n} = 0 \qquad x' \geq 0$$

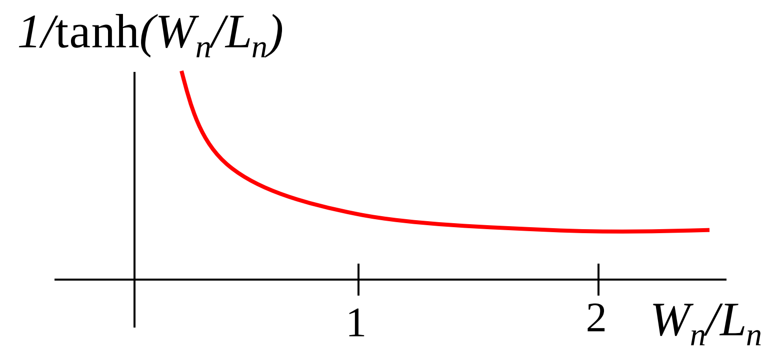
Boundary conditions

$$\Delta p_n(x'=0) = \frac{n_i^2}{N_D}\left(e^{qV_A/kT} - 1\right) \quad (1) \qquad \Delta p_n(x'=W_p) = 0 \ldots (2)$$

$$\Delta p_n(x') = \frac{n_i^2}{N_D}\left(e^{qV_A/kT} - 1\right)\frac{\sinh\left(\left(W_p - x'\right)/L_p\right)}{\sinh\left(W_p/L_p\right)}$$

$$I = A \cdot J = I_0\left(e^{qV_A/kT} - 1\right)$$

$$I_0 = qA\left(\frac{D_n}{L_n \tanh\left(W_n/L_n\right)}\frac{n_i^2}{N_A} + \frac{D_p}{L_p \tanh\left(W_p/L_p\right)}\frac{n_i^2}{N_D}\right)$$



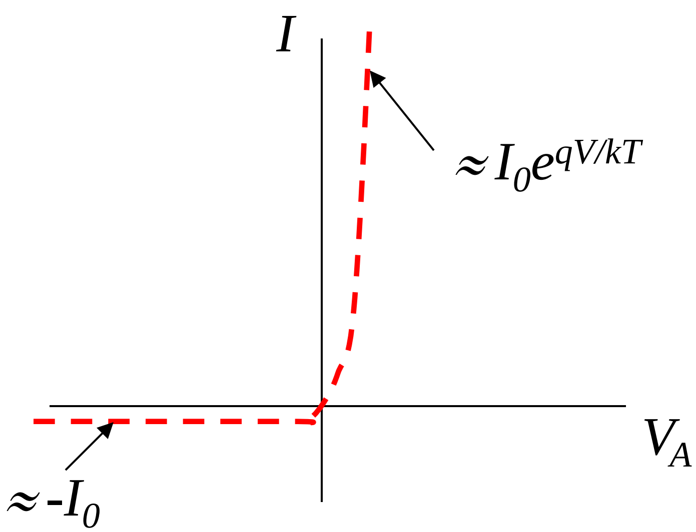
In the "very narrow" base case of $W_n << L_n$ and $W_p << L_p$ (the usual case for submicron technology within a device):

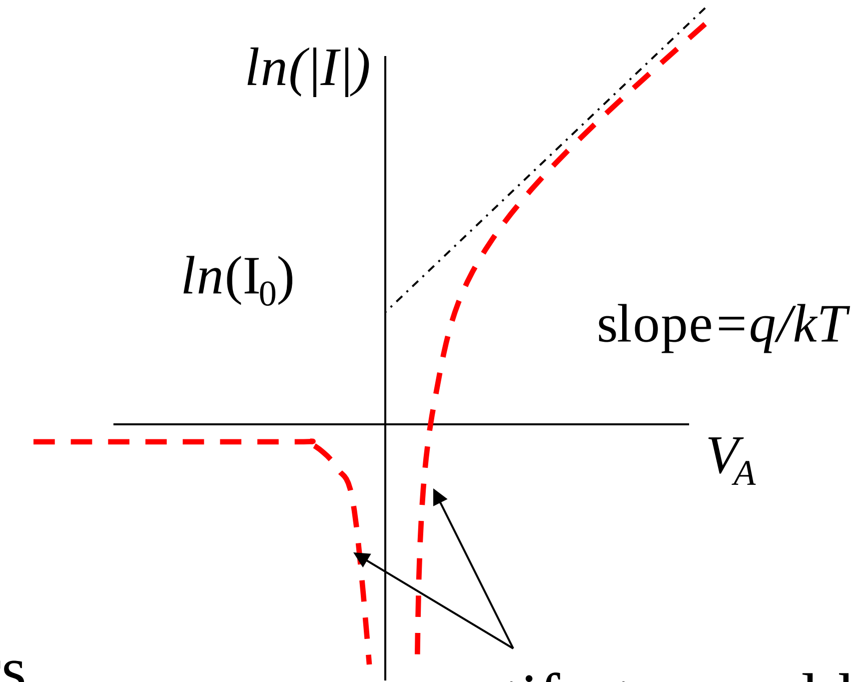
$$I_0 = qA\left(\frac{D_n}{W_n}\frac{n_i^2}{N_A} + \frac{D_p}{W_p}\frac{n_i^2}{N_D}\right)$$

Question 3: HW 6

- Check the shape of E_{Fn} in pn junction in forward bias and reverse bias.
  - Draw band diagram from Poisson Equation
  - Guess the shape of E_{Fn} (assume that E_{Fn} is flat across depletion region coming from n-side)
  - Obtain n(x)
  - Use J_n=constant to get slope of E_{Fn}
  - Compare guess vs final E_{Fn};
  - If same then solutions is consistent between (a) electrostatics (poisson & FD Statistics (approx to MB) and (b) current transport
- The above equation is to obtain n(x) to set up diffusion current in minority carriers. Derive the current for pn junction in forward and reverse bias for short, medium and long base.
  - Short base diode draw Jn(x) and Jp(x)
  - How to increase current in short base diode
  - How to increase current in long base diode
- During current calculation, what enables us to concentrate only in region of only diffusion? Do we know or care (from Jn calculation perspective) whether other regions have drift or diffusion.
  - Estimate drift current and diffusion current in depletion region compared to net current
  - Estimate drift current and diffusion current in majority n region compared to net current
  - Estimate drift current and diffusion current in minority n region compared to net current

Ideal Diode IV in Linear and Log Scales





In the ideal IV equation, most material and geometrical factors are absorbed in I_0.

artifact caused by taking ln of (e^x-1). If y-axis is $\sinh^{-1}(I)$, this unnatural slope will disappear.

$I_0 \propto n_i^2$	$T\uparrow, I_0\uparrow;\ E_{gap}\uparrow, I_0\downarrow$
$I_0 \propto 1/N_D$	$N_D\uparrow, I_0\downarrow$
$I_0 \propto 1/L_n$	$L_n\downarrow, I_0\uparrow$
$I_0 \propto 1/W_n$	$W_n\downarrow, I_0\uparrow$