Essentials of MOSFETs

Unit 5: Additional Topics

Lecture 5.4: Review of PN Junctions

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Transistors

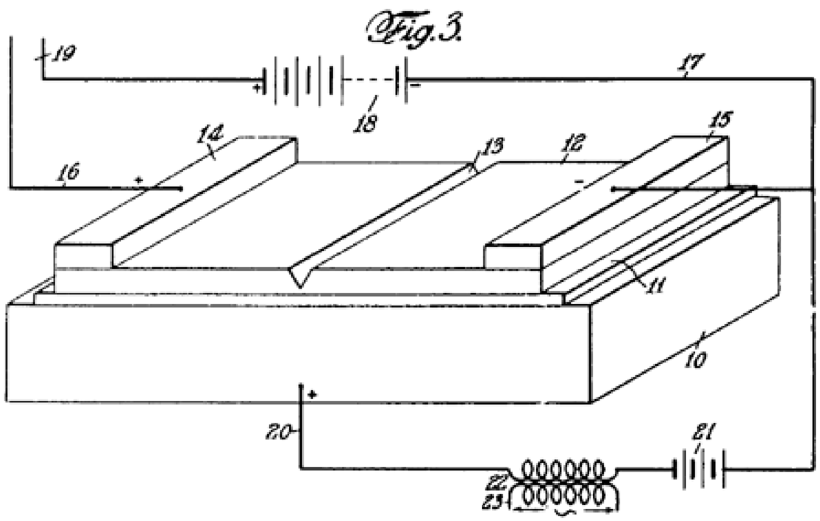
MOSFET
MOST
IGFET
DMOS
HEXFET
VMOS
TFT
MISFET
JFET
VFET
MESFET
MOSFET
HEMT
TEGFET

HFET
DHFET
HIGFET
SISFET
PBT
LRTFET
VMT
BJT
HBT
DHBT
THETA
RST
BICFET
RTBT

RBT
RHET
QWBRTT
TETRAN
SIT
NWFET
CNT FET
SB FET
BTBT FET
induced base transistor
planar doped barrier transistor
metal base transistor
Stark-effect transistor
delta-doped channel heterojunction FET

Bipolar transistors are barrier-controlled transistors too.

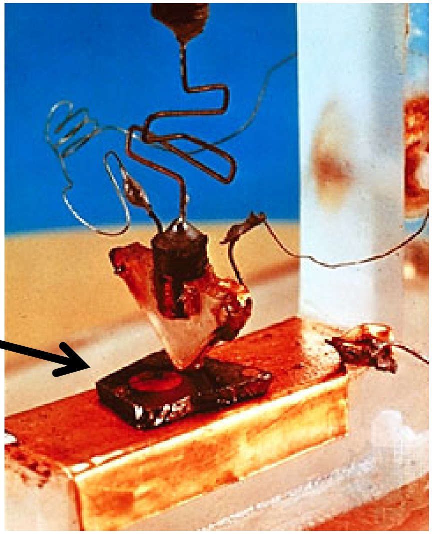
Invention (and discovery) of the transistor



Field-Effect Transistor
Lillienfield, 1925
Heil, 1935

Bardeen, Schockley,
and Brattain, 1947

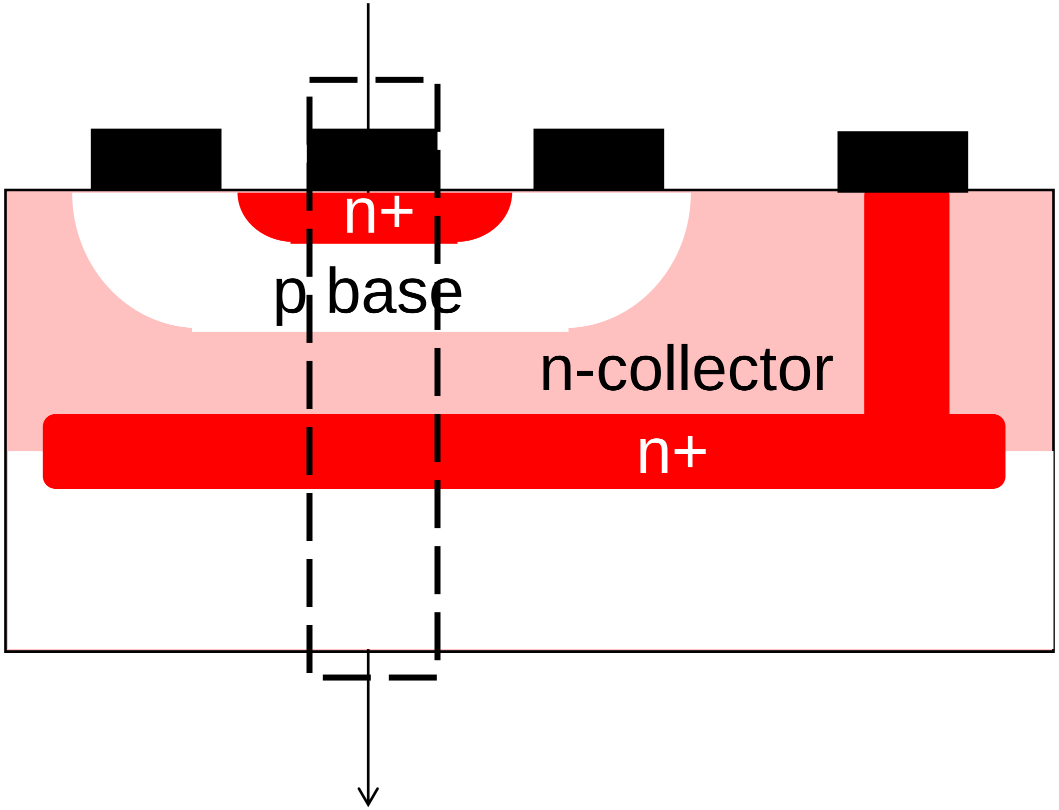
“base”



Lucent / Bell Labs

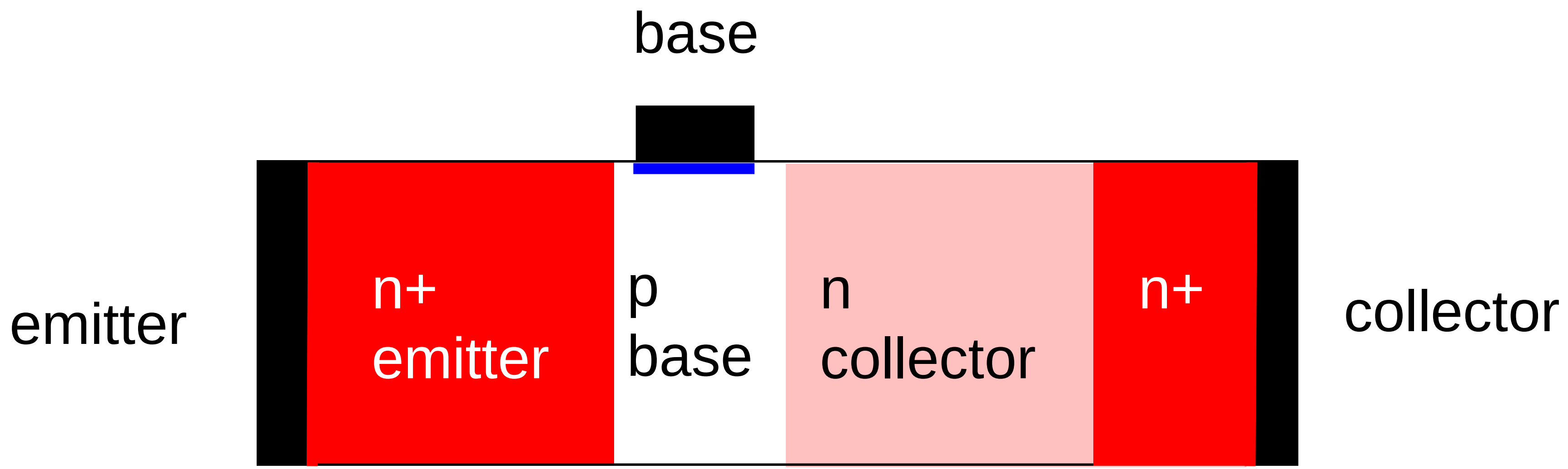
Bipolar transistors

Double diffused Bipolar Junction Transistor (BJT)



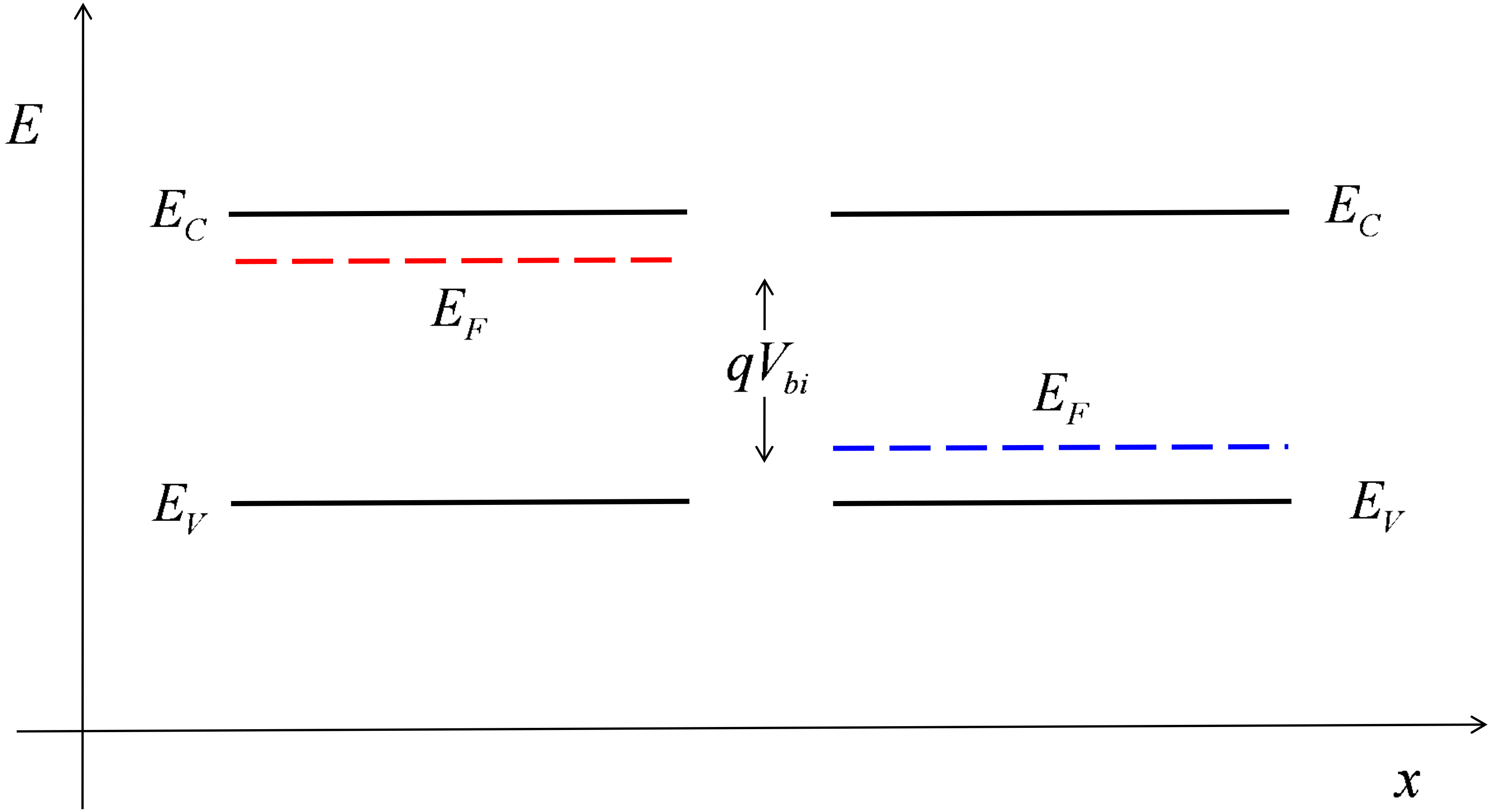
"ideal" 1D BJT

Bipolar transistors



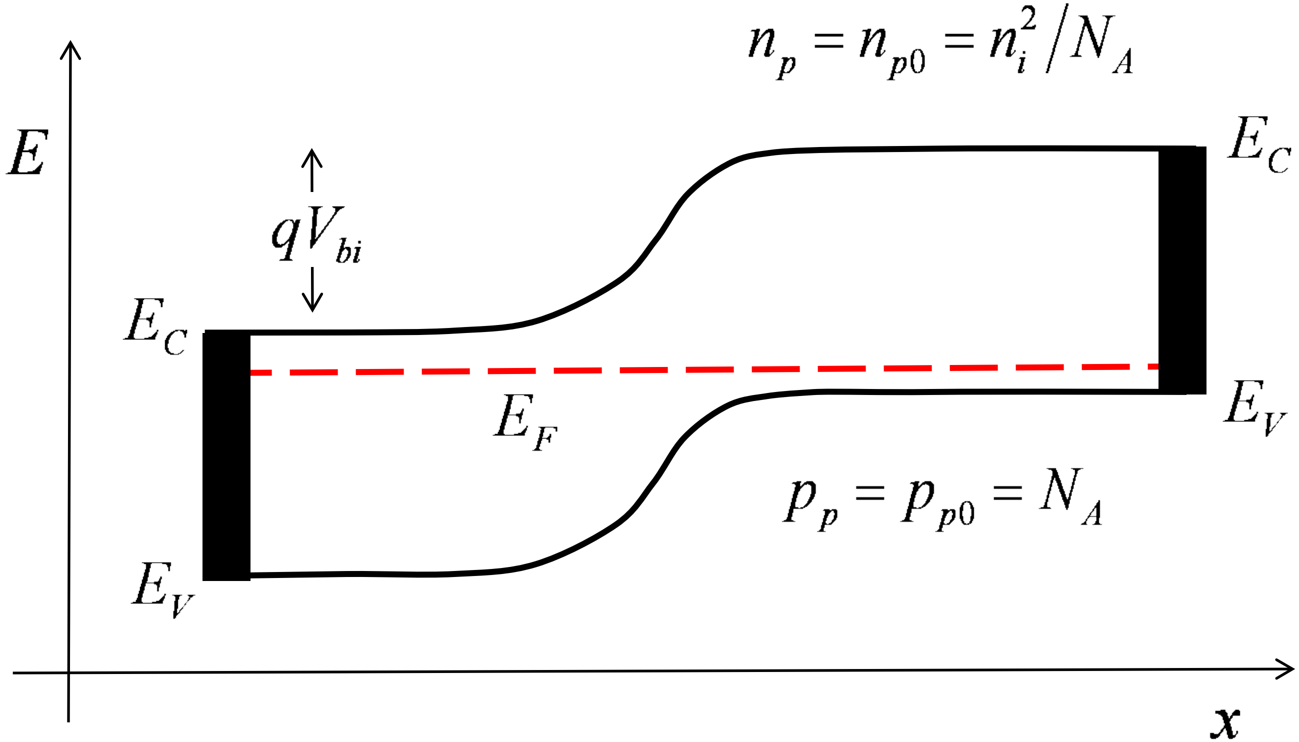
Just as the MOS-C is the heart of a MOSFET, BJT's are made up of a basic building block: The PN junction.

Primer on PN junctions



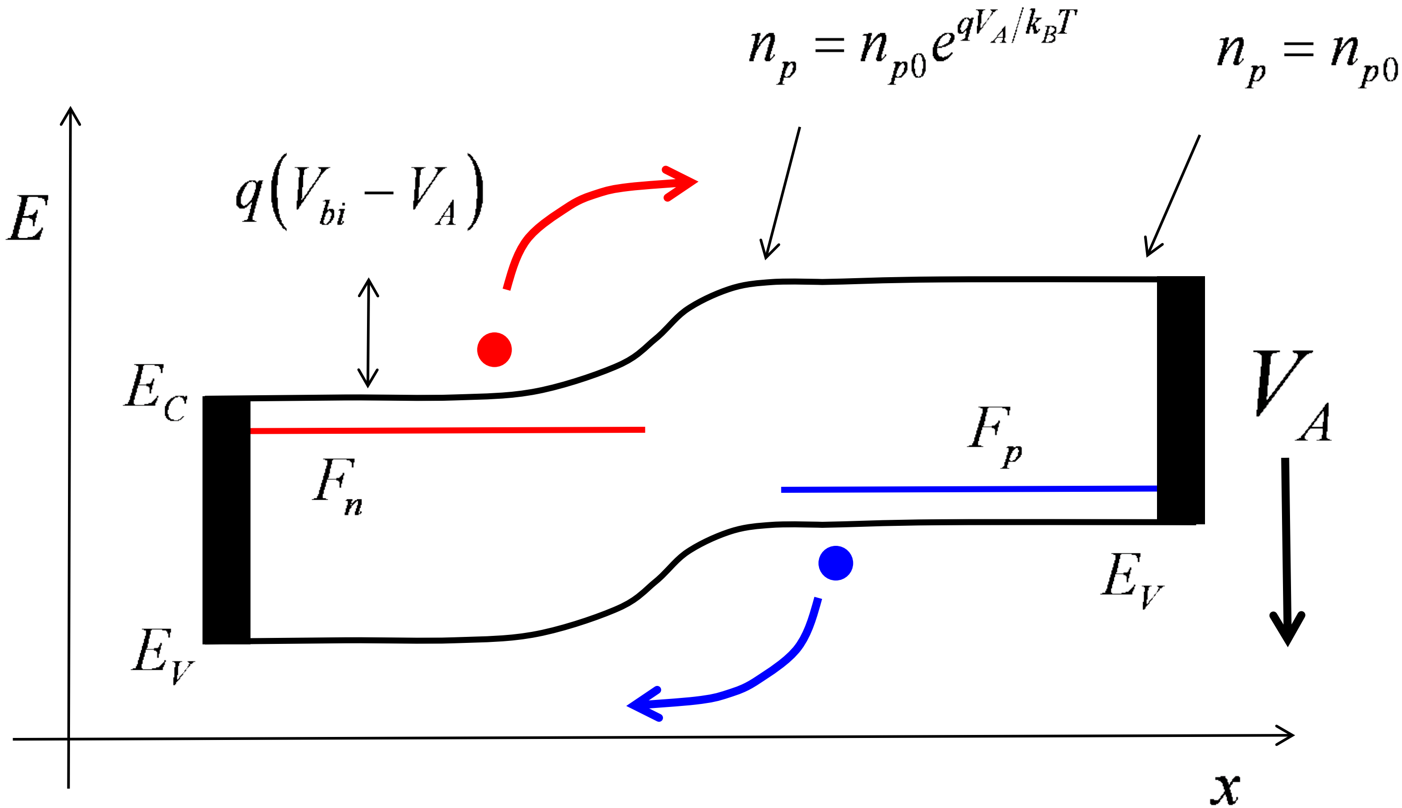
Lundstrom: 2018

Equilibrium energy band diagram



(equilibrium)

Forward bias



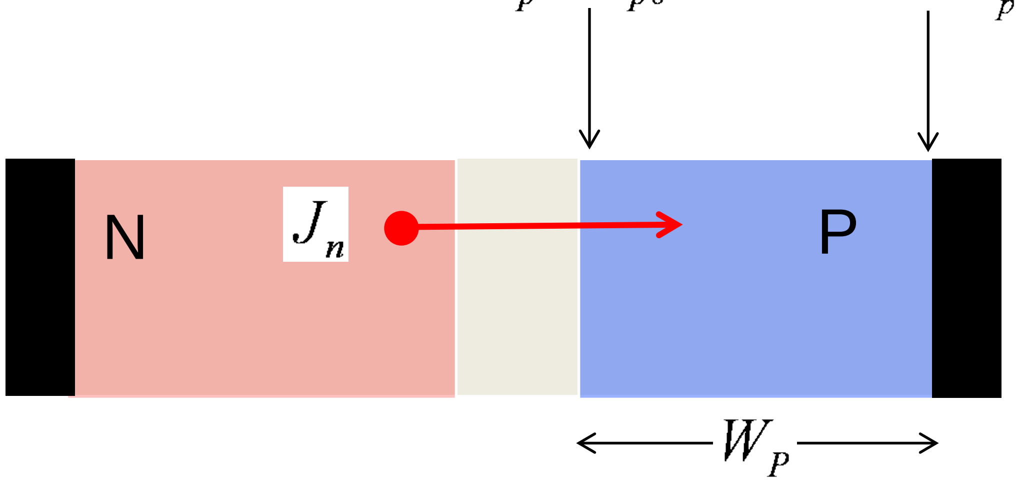
(forward bias)

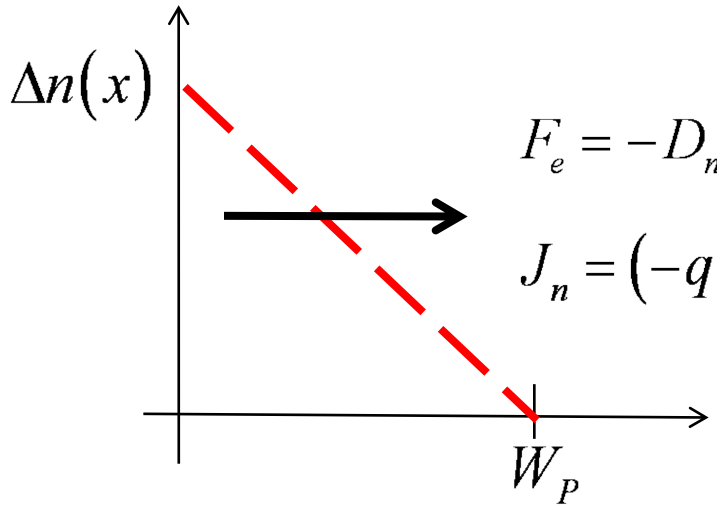
Lundstrom: 2018

Electron current in a FB PN junction

$$n_p = n_{p0} e^{qV_A/k_BT}$$

$$n_p = n_{p0} = \frac{n_i^2}{N_A}$$





$$F_e = -D_n \frac{d\Delta n}{dx}$$

$$J_n = (-q) F_e$$

$$\Delta n_p(0) = n_{p0}\left(e^{qV_A/k_BT} - 1\right)$$

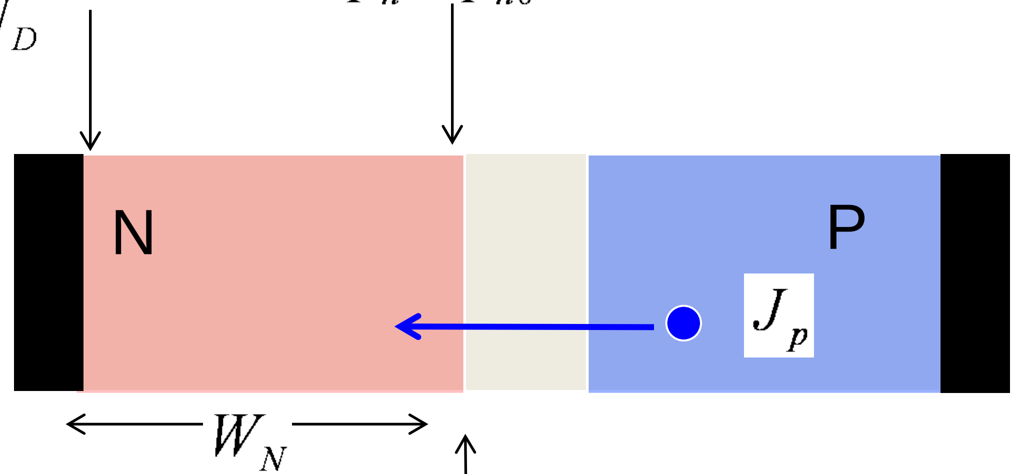
$$J_n = q n_{p0} \frac{D_n}{W_P}\left(e^{qV_A/k_BT} - 1\right)$$

(magnitude of current)

Hole current in a FB PN junction

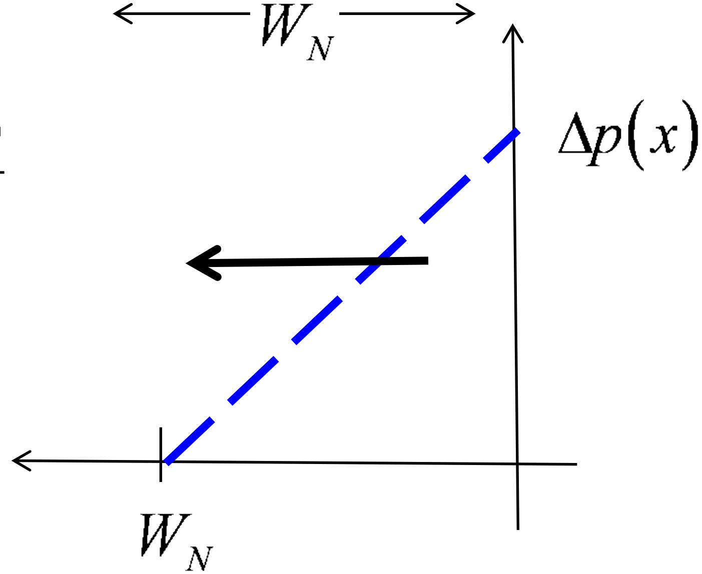
$$p_n = p_{n0} = \frac{n_i^2}{N_D}$$

$$p_n = p_{n0} e^{qV_A/k_BT}$$



$$F_h = -D_p \frac{d\Delta p}{dx}$$

$$J_p = (+q) F_h$$

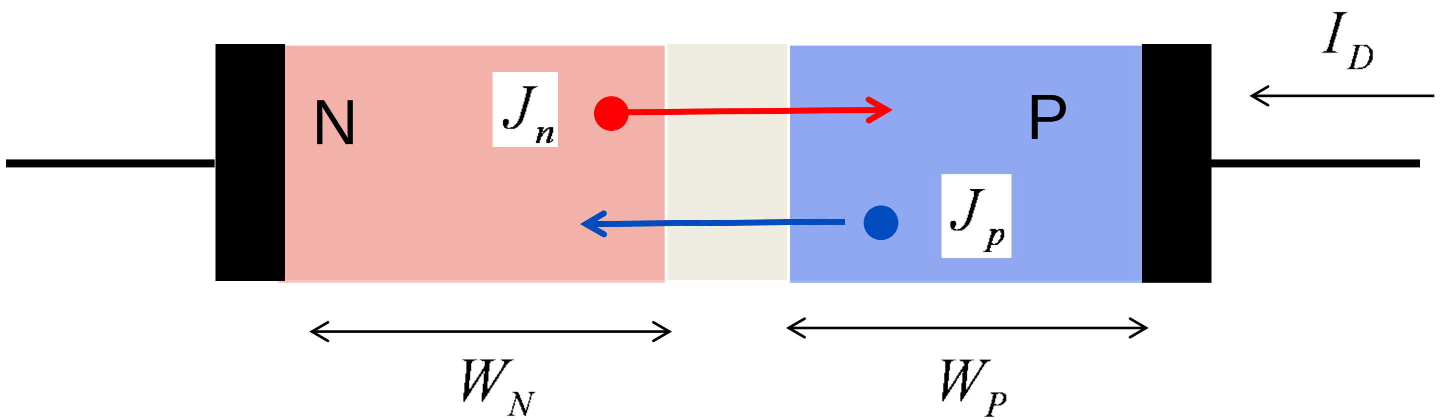


$$\Delta p_n(0) = p_{n0}\left(e^{qV_A/k_BT} - 1\right)$$

$$J_p = q p_{n0} \frac{D_p}{W_N}\left(e^{qV_A/k_BT} - 1\right)$$

(magnitude of current)

Current in a FB PN junction

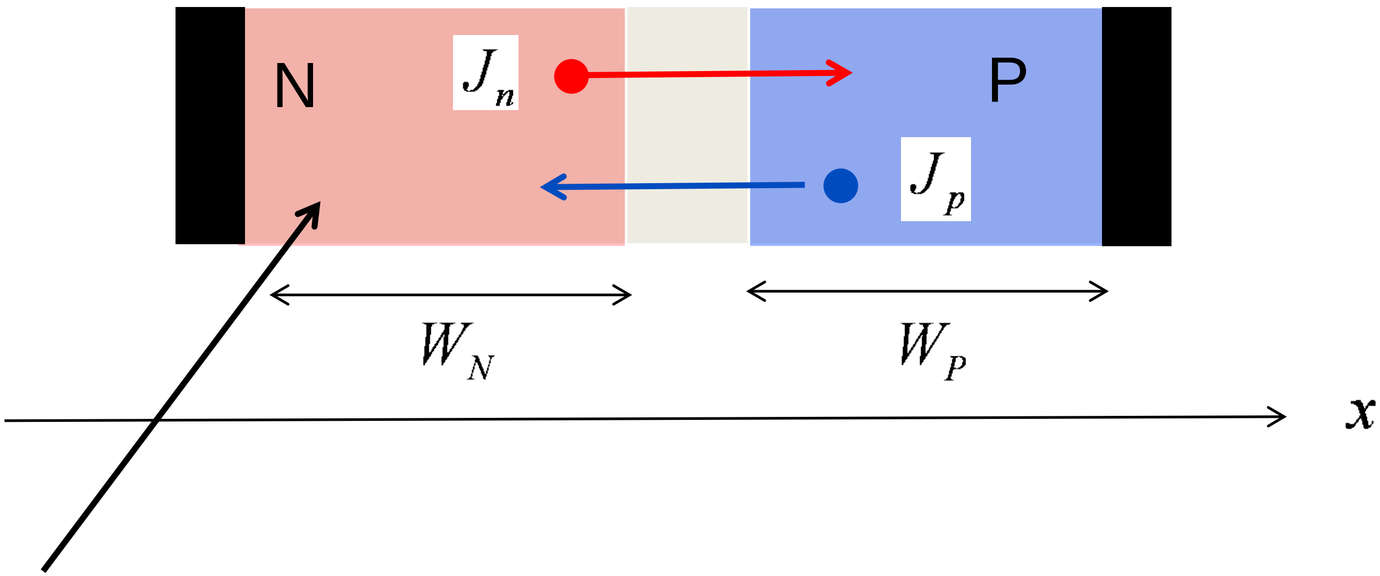


$$J_n = q\frac{D_n}{W_P}\frac{n_i^2}{N_A}\left(e^{qV_A/k_BT}-1\right)$$

$$J_p = q\frac{D_p}{W_N}\frac{n_i^2}{N_D}\left(e^{qV_A/k_BT}-1\right)$$

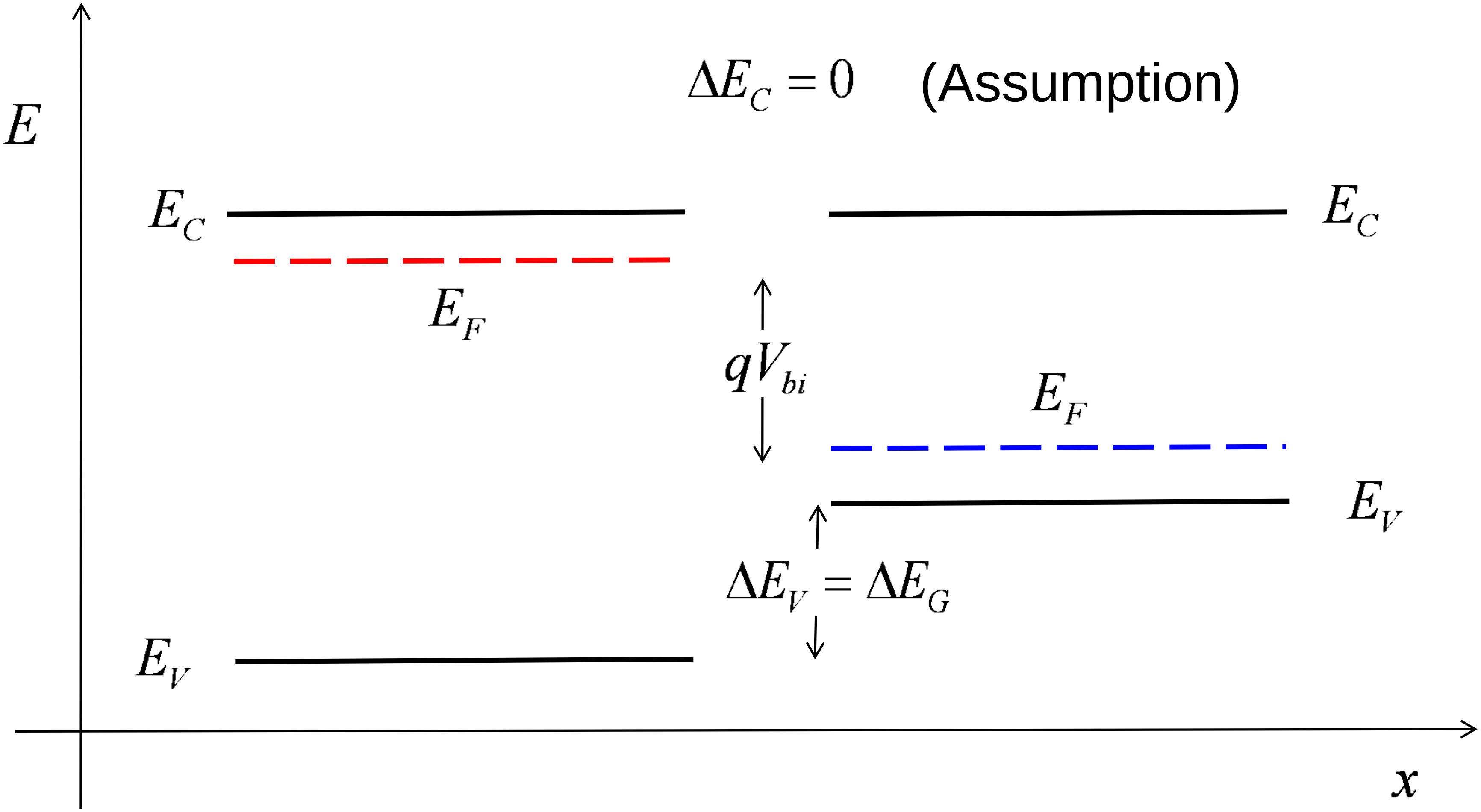
$$I_D = A_D\left(J_n + J_p\right)$$

Heterojunction diodes

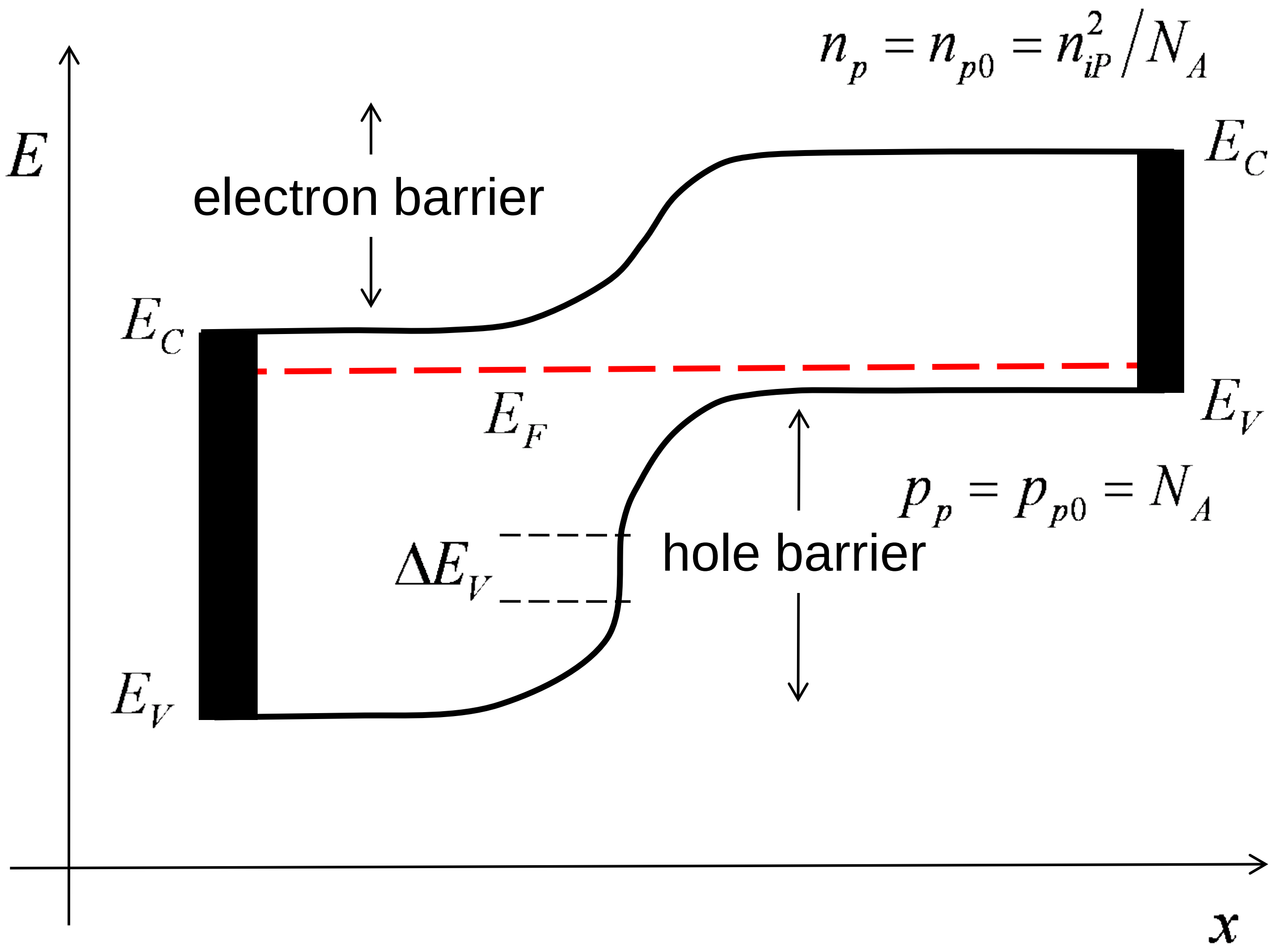


$E_{GN} > E_{GP}$

Np heterojunction

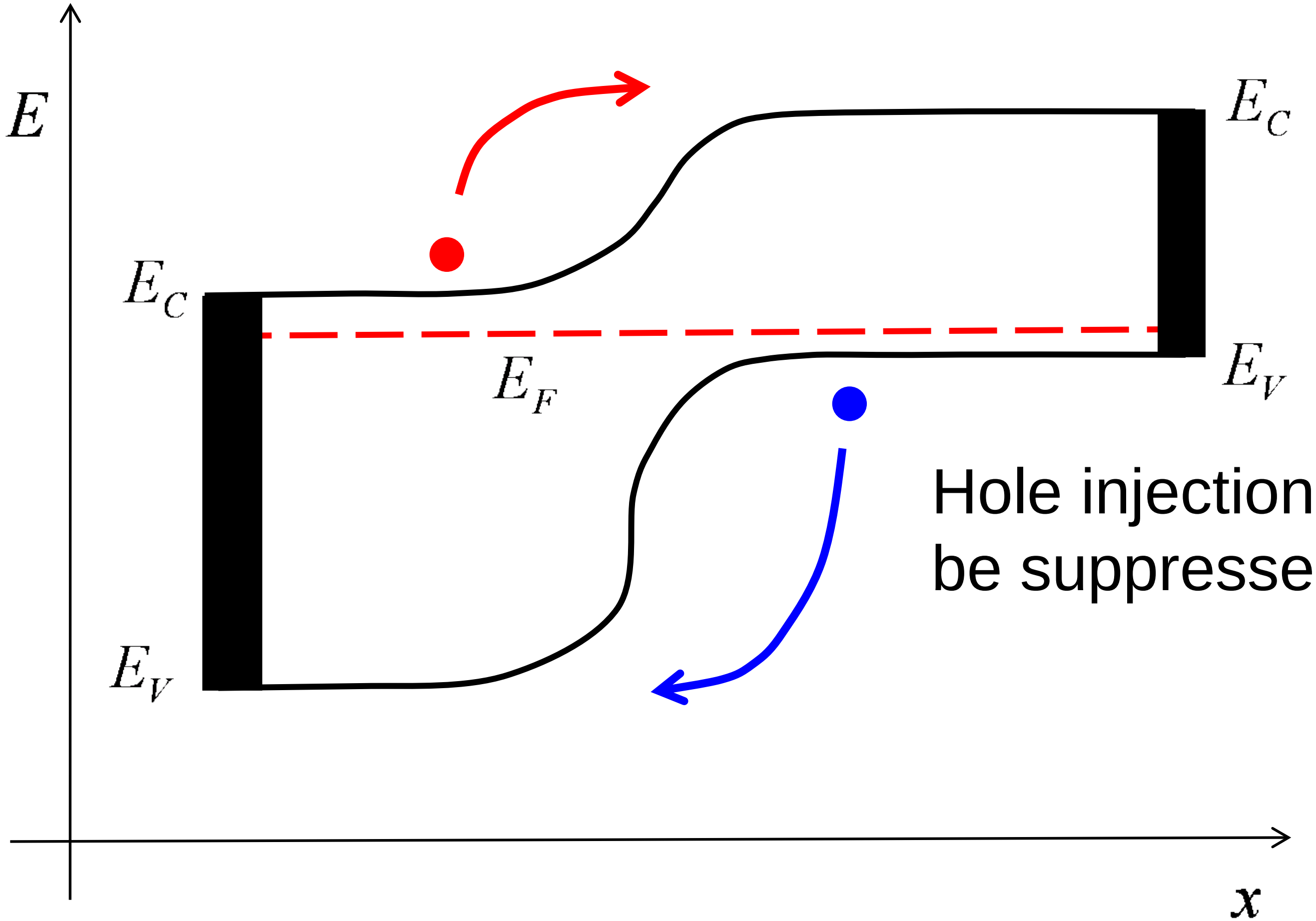


Equilibrium energy band diagram



Lundstrom: 2018

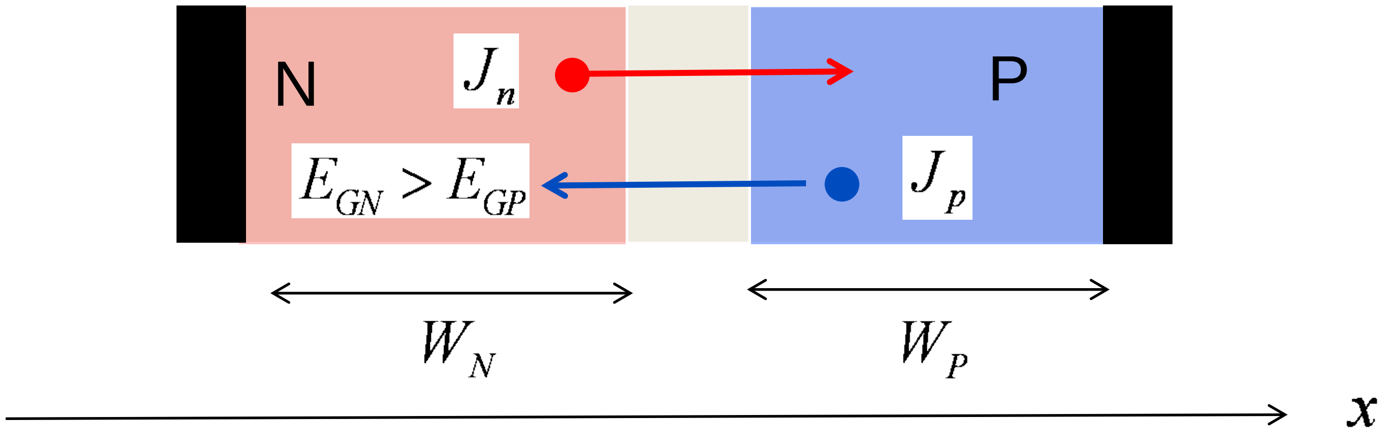
Equilibrium energy band diagram



Hole injection will be suppressed

Lundstrom: 2018

Current in a FB Np heterojunction



$$J_n = q\frac{D_n}{W_P}\frac{n_{iP}^2}{N_A}\left(e^{qV_A/k_BT}-1\right)$$

$$J_p = q\frac{D_p}{W_N}\frac{n_{iN}^2}{N_D}\left(e^{qV_A/k_BT}-1\right)$$

$$n_i^2 \propto e^{-E_G/k_BT}$$

$$E_{GN} > E_{GP}$$

$$n_{iN}^2 << n_{iP}^2$$

$$J_p << J_n$$

Summary

1) PN diodes are bipolar devices – current is due to electrons and holes.

2) A forward bias lowers the barrier for electron and hole injection (i.e. it is a barrier-controlled device).

3) The current increases exponentially with forward bias (a 60 mV increase in FB increases I_D by 10X).

4) It is possible to suppress one of the two current components by using heterojunctions.

Next topic

An NPN bipolar transistor consists of two PN junctions with a shared P region.

Since we understand PN junctions, we can understand BJTs.

That is our topic for the next lecture.