# EEE105
# “Electronic Devices”

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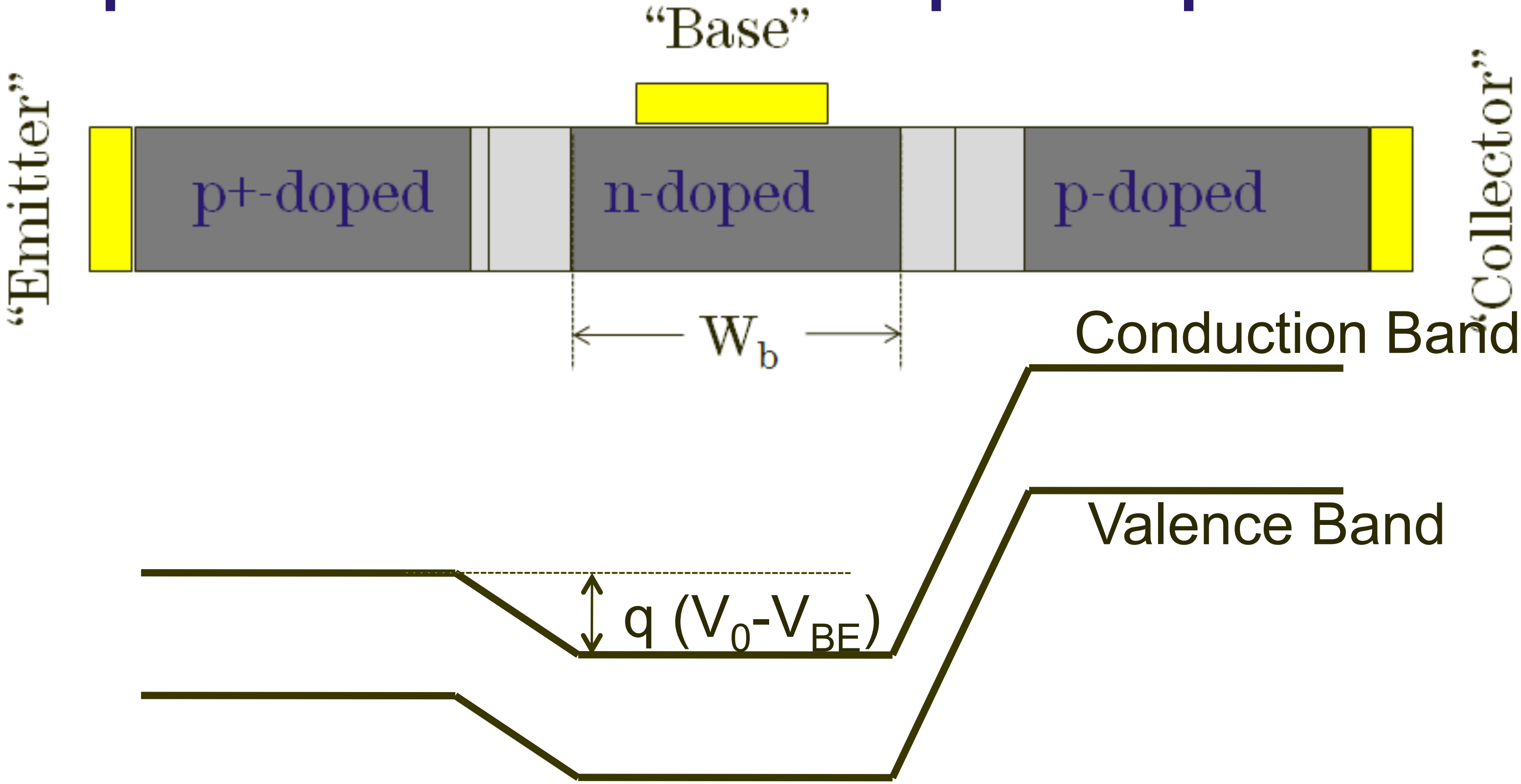
# Lecture 19

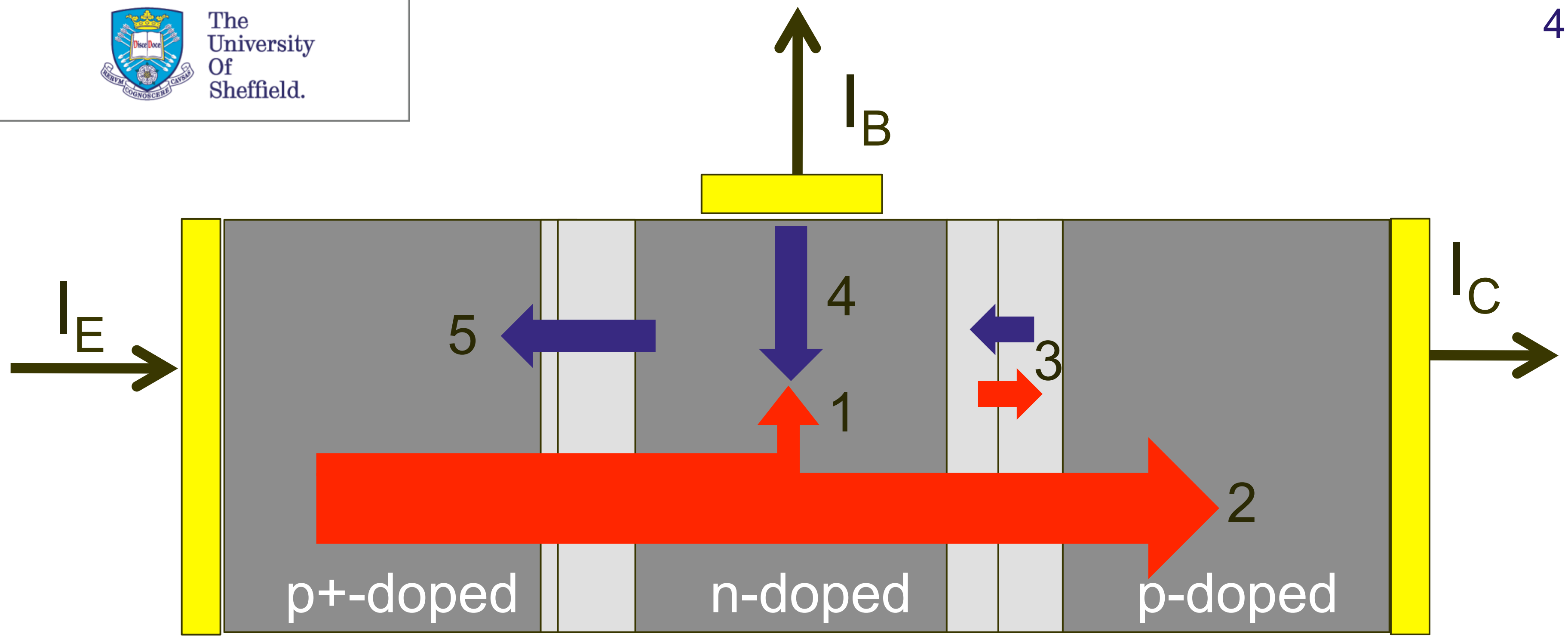
- BJT – review of assumptions
- Base Narrowing – Early Effect
- Avalanche Breakdown
- Kirk Effect

# Operational Bias – p+-n-p




$V_{BE}$ determines Emitter and Collector current




Have asymmetric doping to give “minority carrier injector” to a p-n diode
Base width is much less than minority carrier diffusion length to ensure maximal current transfer to collector
Have not considered effects of varying bias on depletion layer thicknesses
Have not worried about reverse breakdown of base-collector
Have neglected effect of large injected carrier densities
Have neglected effects of self-heating

# The Early Effect

So far have assumed Base width is independent of bias - not true!

As reverse bias on base-collector increases the depletion region width increases. – Named after J.M. Early, also known as base modulation, narrowing

$$x_{n0} = \frac{W N_a}{(N_d + N_a)}$$

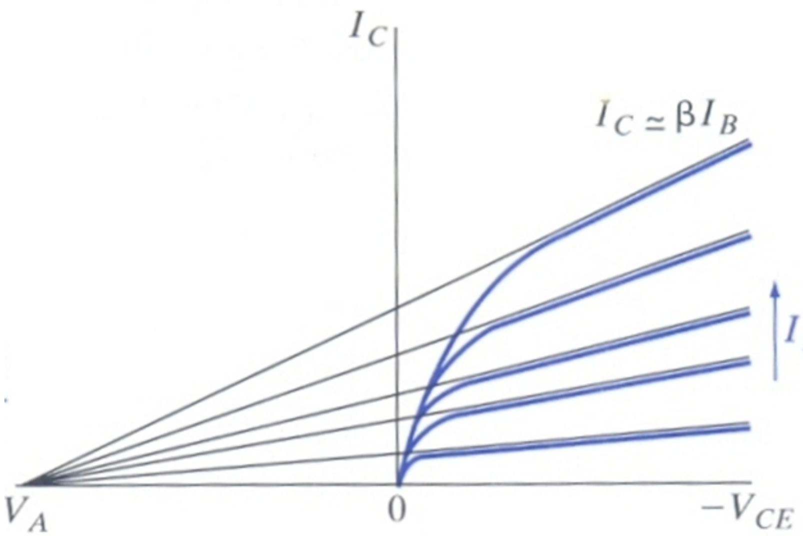
$$W = \left[\frac{2\varepsilon(V_0 - V_f)}{q}\left(\frac{N_a + N_d}{N_a N_d}\right)\right]^{1/2}$$

$$x_{p0} = \frac{W N_d}{(N_d + N_a)}$$

# (a.k.a. Base narrowing)

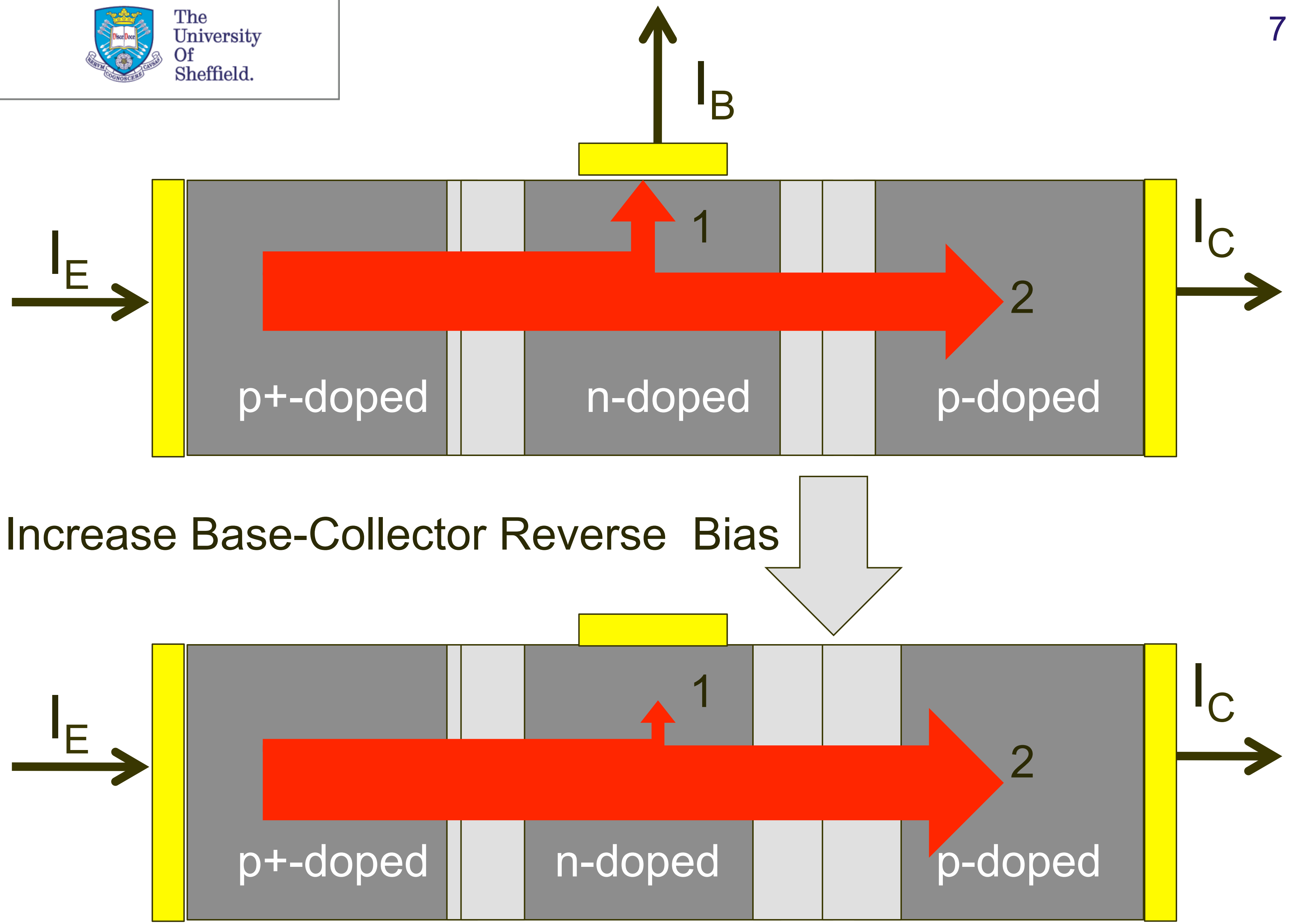





Observed increase in β at high $V_{CE}$

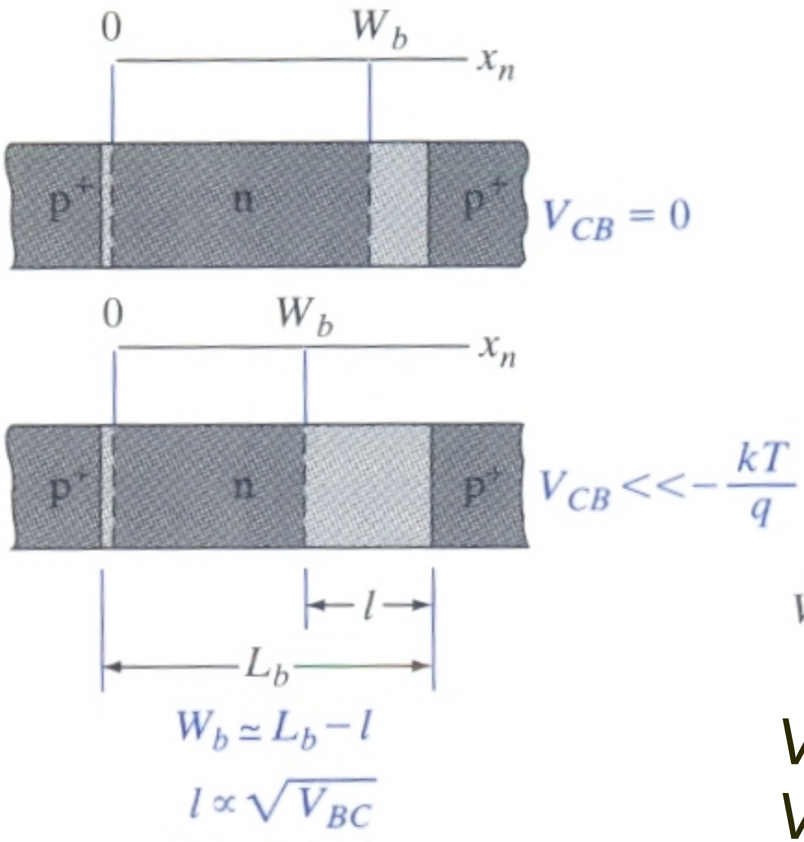
Due to reduction in base width, reduced recombination of minority and majority carriers, increased base transport factor "B "

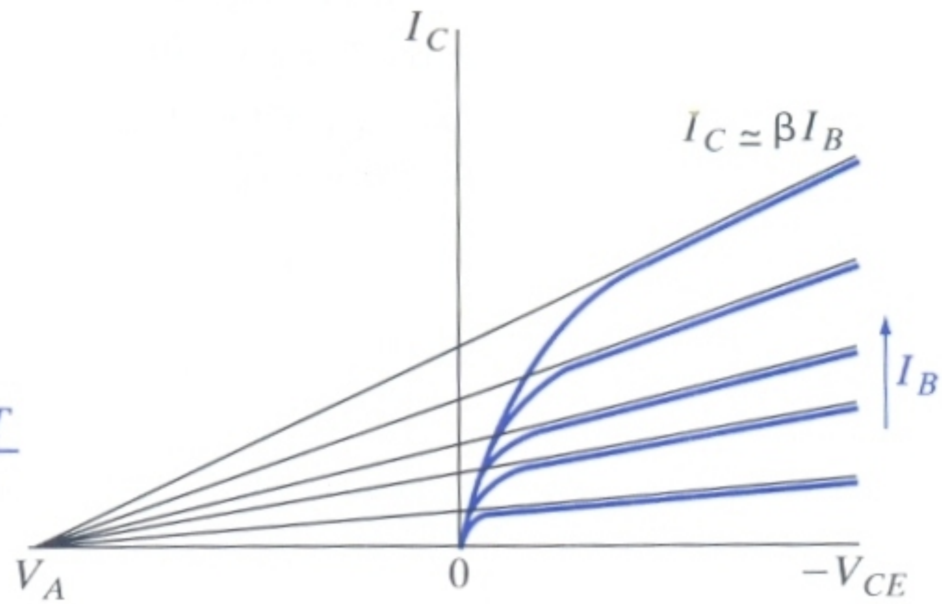
$$\frac{i_C}{i_B} = \frac{B\gamma}{1 - B\gamma} = \frac{\alpha}{1-\alpha} \equiv \beta$$



$I_B$
$I_E$
1
2
$I_C$
p+-doped
n-doped
p-doped
Increase Base-Collector Reverse Bias
$I_E$
1
2
$I_C$
p+-doped
n-doped
p-doped




$$\beta_F = \beta_{F0}\left(1 + \frac{V_{CE}}{V_A}\right)$$

$V_{CE}$ is the collector–emitter voltage
$V_A$ is the **Early voltage** (typically 15 V to 150 V)
$\beta_{F0}$ is forward common-emitter current gain at zero bias.

# Calculating Base Narrowing (I)

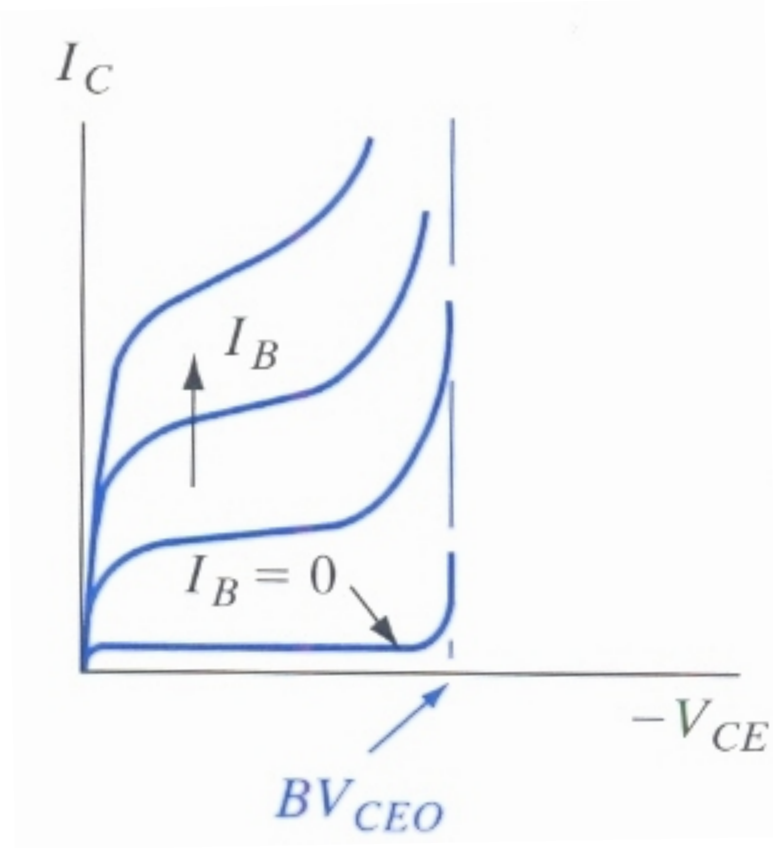
$$x_{n0} = l = \frac{W\,N_a}{\left(N_d + N_a\right)} \qquad W = \left[\frac{2\varepsilon\left(V_0 - V_{CB}\right)}{q}\left(\frac{N_a + N_d}{N_a N_d}\right)\right]^{1/2}$$

$V_{CB}$ is big and negative so $V_0$-$V_{CB}$ ~$V_{CB}$

$$l^2 = W^2\left(\frac{N_a}{N_d + N_a}\right)^2 = \frac{2\varepsilon\left(V_{CB}\right)}{q}\left(\frac{\cancel{N_a + N_d}}{\cancel{N_a} N_d}\right)\left(\frac{\cancel{N_a}}{\cancel{N_d + N_a}}\right)\left(\frac{N_a}{N_d + N_a}\right)$$

$$l = \left[\frac{2\varepsilon\left(V_{BC}\right)}{q}\left(\frac{N_a}{N_d\left(N_a + N_d\right)}\right)\right]^{1/2}$$

# Avalanche Breakdown



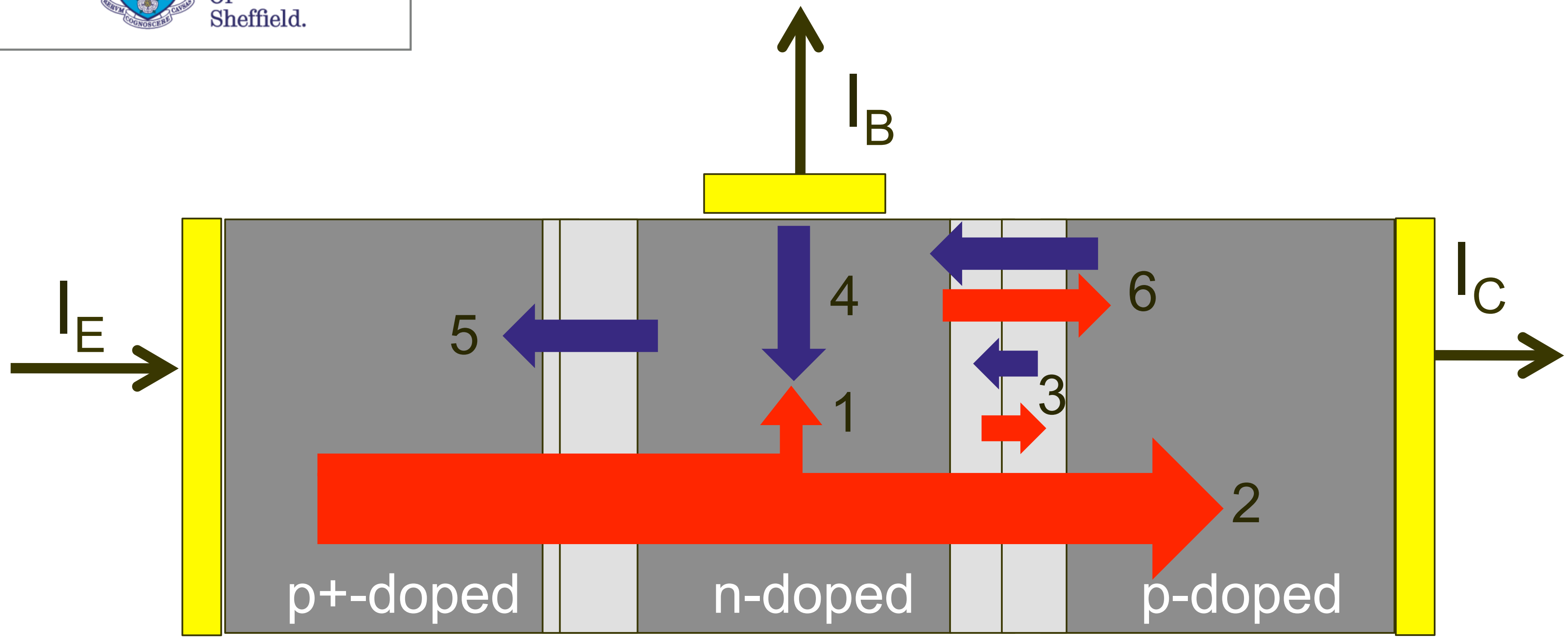

Avalanche for high reverse biases

Super-linear increase in current due to impact ionization and current multiplication

Particularly important for Common Emitter configuration

Majority carriers created in base – large leverage to emitter current



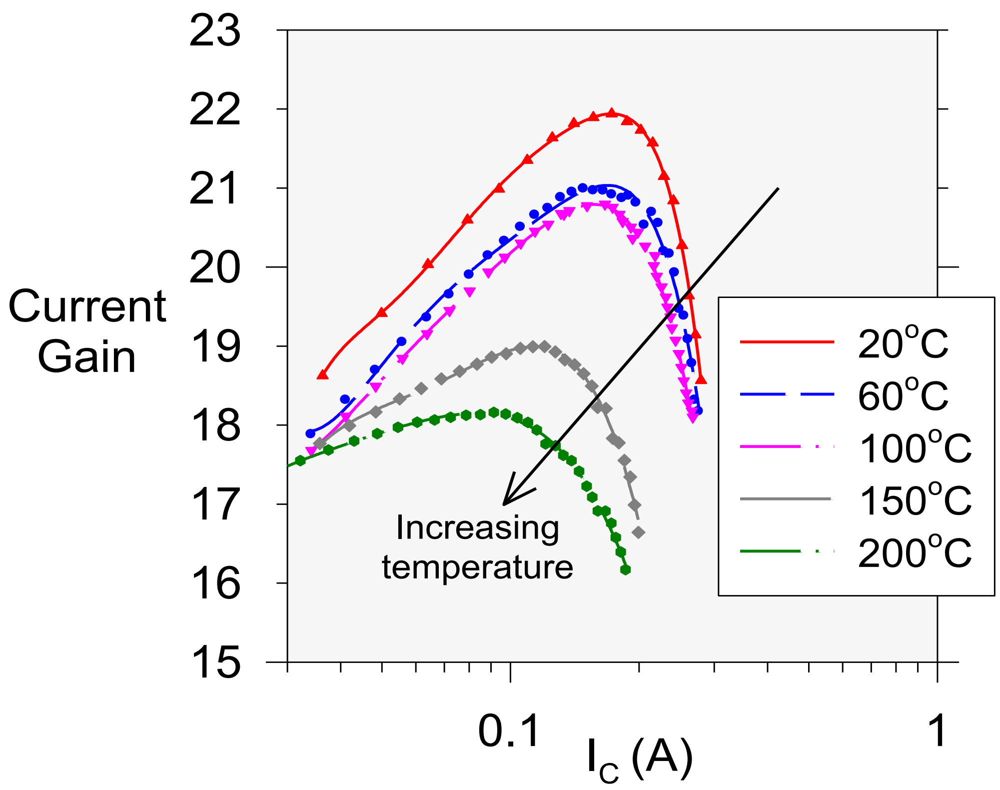

Under avalanche – get multiplication of hole collector current – creates both electrons and holes

Electrons added to base need charge balancing – extra holes “sucked/dragged” through base

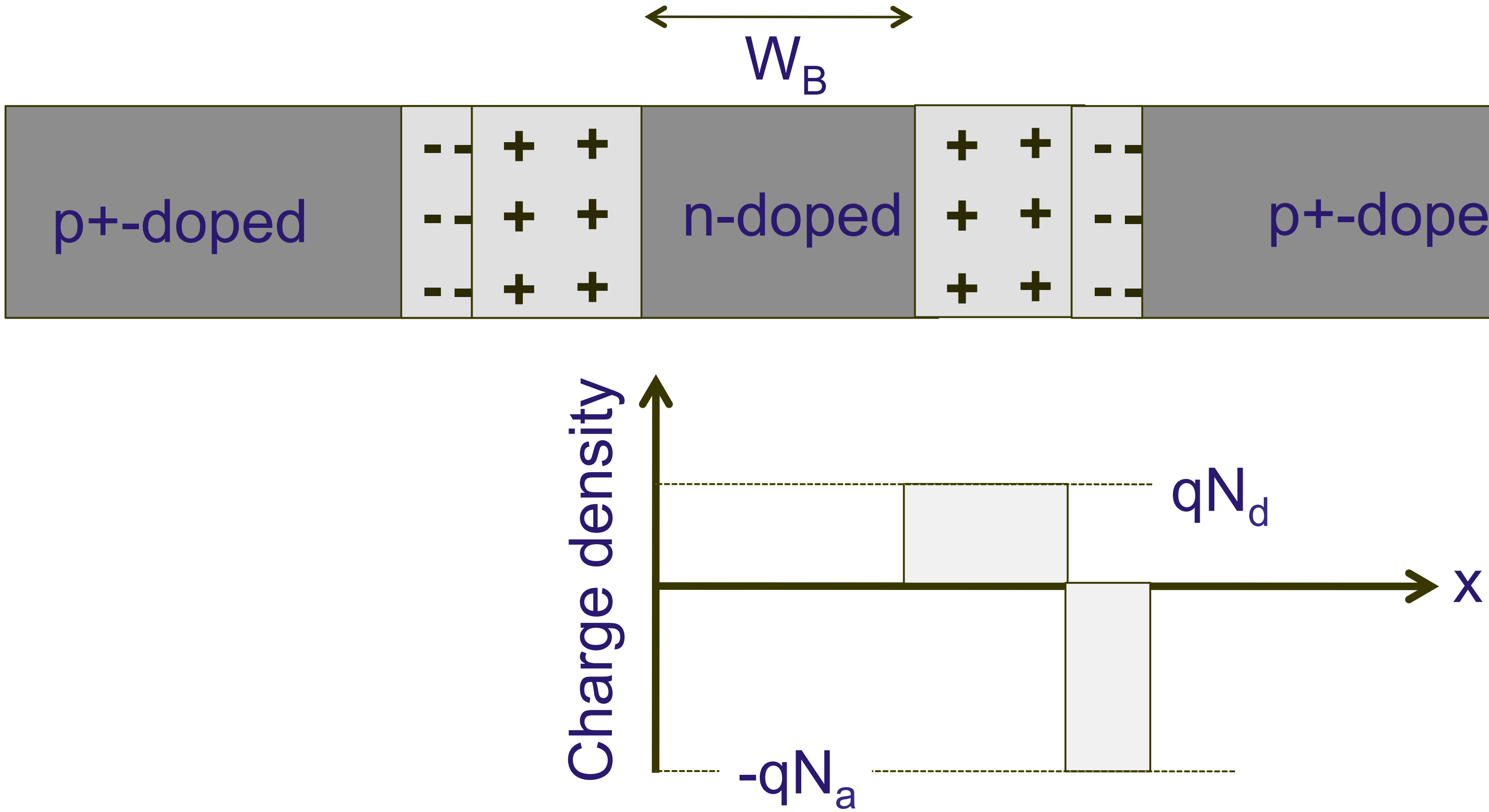
# Kirk Effect

- Observation – current gain reduction at high collector currents.

- Data is for a DHBT courtesy of P.A. Houston



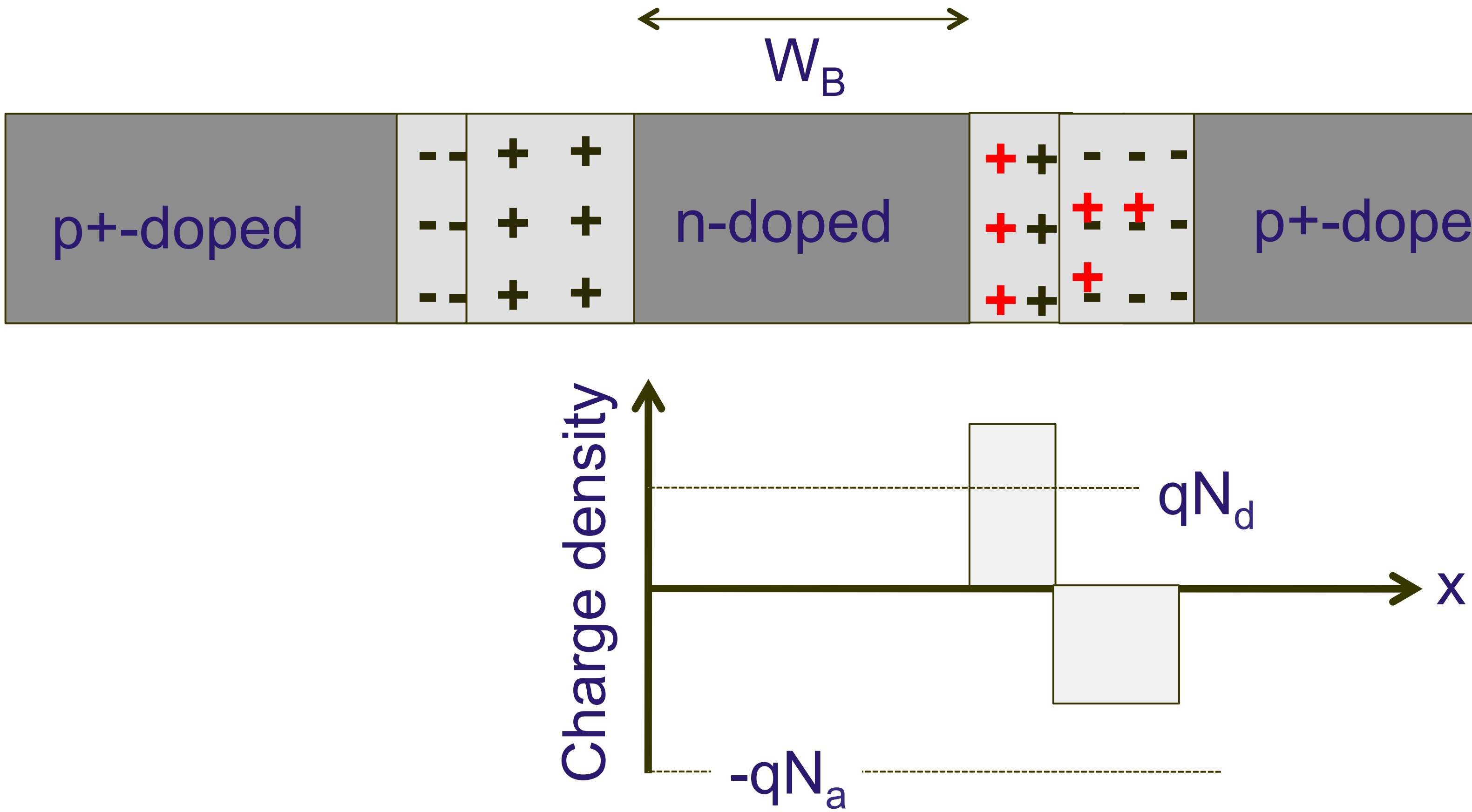

 




Large hole current acts as a space charge – compensated in base by base current (or caused by it!)

What happens when hole current density is similar to doping density?




Large hole current - same sign as on base side of base-collector junction – junction shrinks on this side

Oposite sign as on collector side – larger depletion region

Base gets wider – reduced Base transport factor reduces

Current amplification factor $\beta$

# Summary

- Discussed assumptions made in previous discussions on operation of BJT
- The Early effect describes base narrowing which tends to increase current  amplification factor, $\beta$, due to an increase in base transport factor, B.  The Early voltage needs to be used to predict $\beta$ accurately.
- Avalanche breakdown may also occur of the reverse bias across the base-collector junction is high.  The injection of majority carriers to the base can result in very large (possibly catastrophic) increases in collector current.
- The Kirk effect describes high current effects which alter the distribution of space charge in the depletion regions.  At high collector currents the base width increases as the depletion region position is altered.