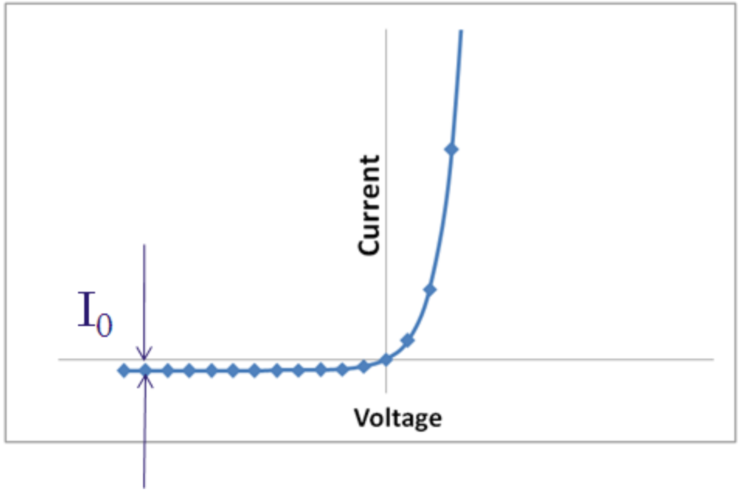
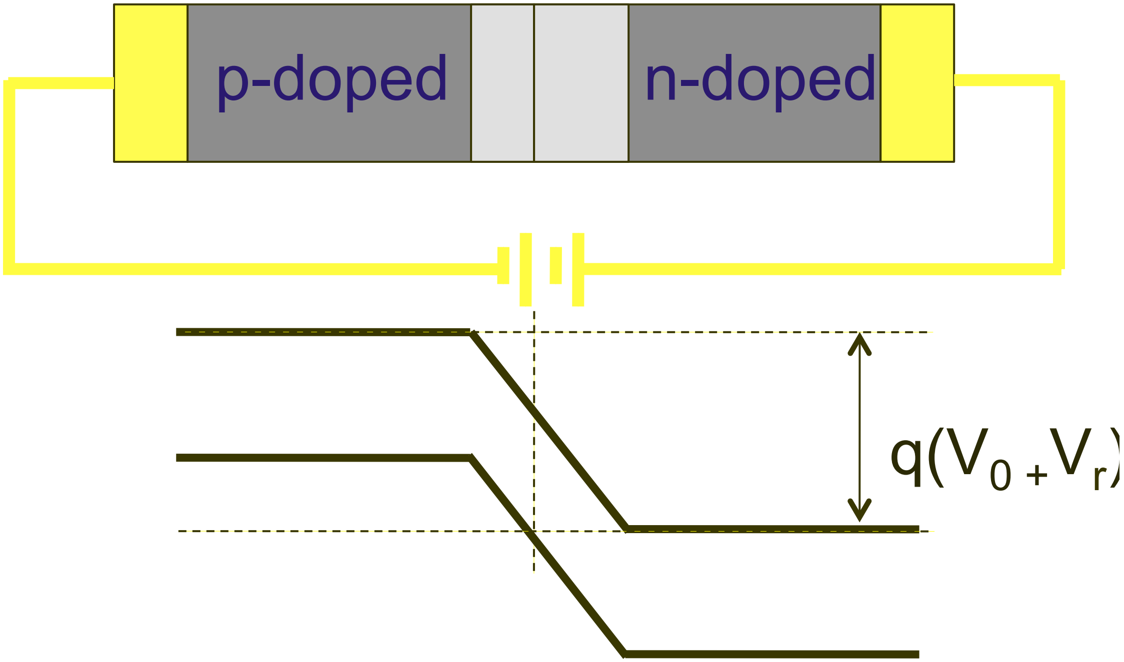
Lecture 17

- p+n junctions under forward and reverse bias – minority carrier injection
- Two back-to-back p+n junctions
- Bipolar Junction Transistor (BJT) action

Reverse Bias pn diode





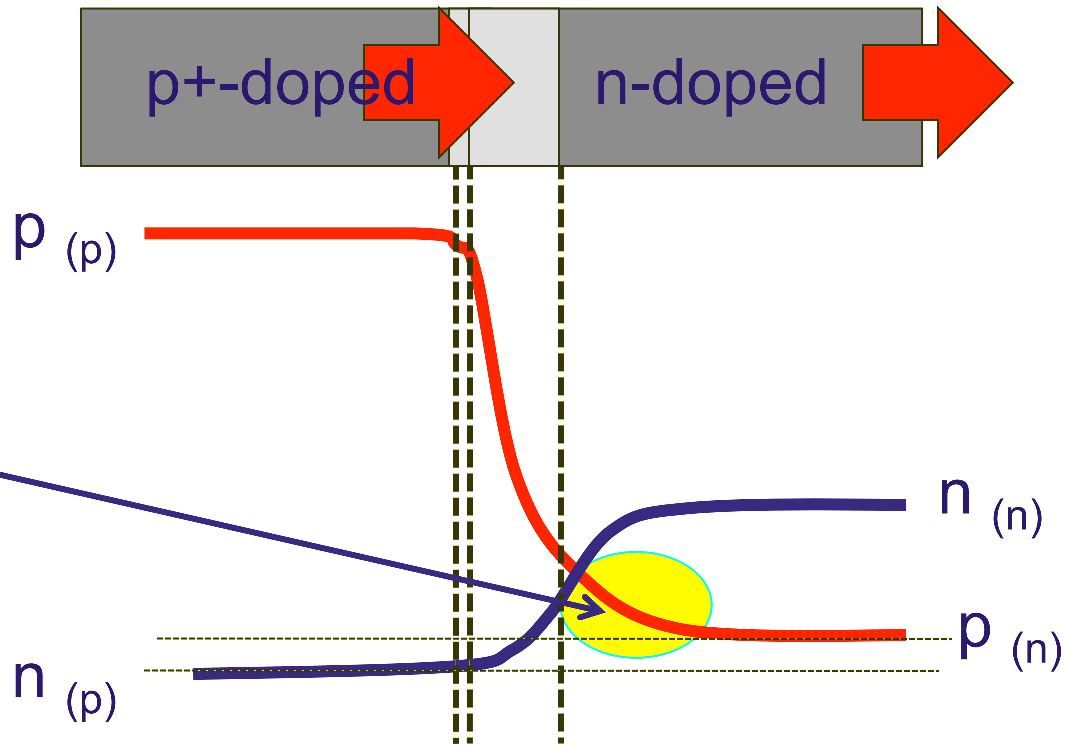
At high reverse voltage V_r:

• (Small) Reverse current is entirely due to thermally generated minority carriers in (and close to) the depletion region

Forward biased diode p$^+$-n diode

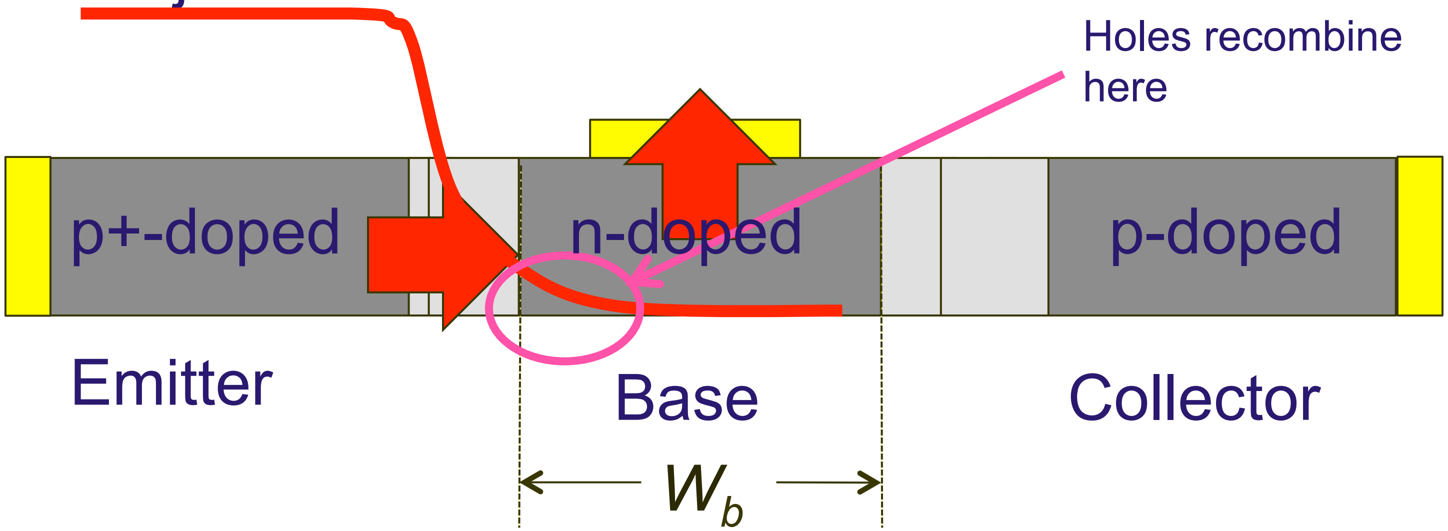
If p-doping is >>n-doping, majority of diode current is due to holes (n.b. can make n+p too for electron dominated current)

- These holes are injected into the n-doped side as excess minority carriers
- They then recombine with the large number of electrons there
- Electrons flow in from the n-region contact to replace those lost from recombination



Combine two p+n diodes

Emitter-base junction diode forward biased, base-collector junction diode reverse biased

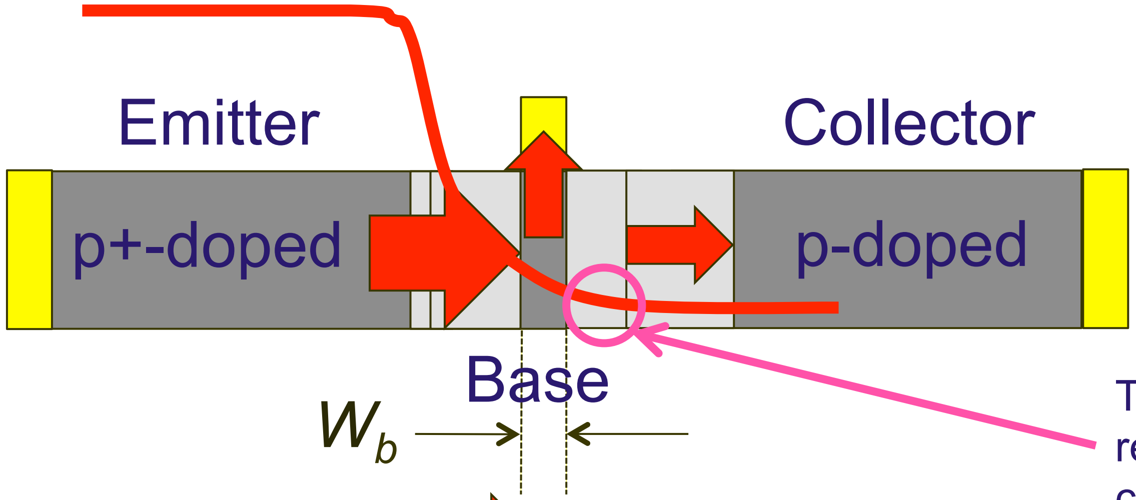


• Holes are injected into base (➡) and recombine with the majority electrons
• Electrons from the base contact flow in (conventional current flows out) to replace electrons lost by recombination
• Reverse biased base-collector junction unaffected (small current).

The University Of Sheffield.

Reduce Base Thickness

Emitter-base junction diode forward biased, base-collector junction diode reverse biased



These holes make it to the reverse biased base collector depletion region

- Holes are injected into base ( )
- Some recombine with the majority electrons in the n-type base
- Electrons from the base contact flow in (conventional current flows out) to replace electrons lost by recombination
- Remaining holes diffuse to the base-collector depletion region before they recombine and are pulled into the collector region by the built-in electric field there
- These holes appear as current in the collector terminal
- The emitter-base bias therefore controls the collector current – transistor action

Required Base Width

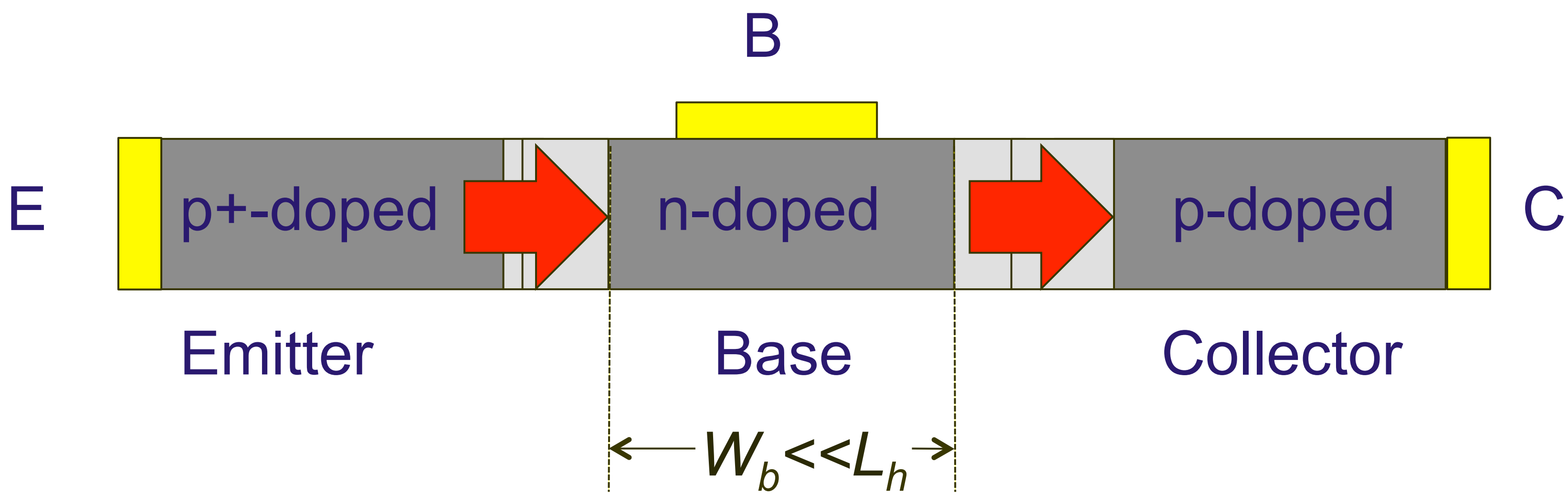
We will see later that good transistor action occurs when most of the injected holes reach the collector depletion region without recombining with the electrons in the base. To ensure this, the base width, W_b, needs to be thin – how thin?

We saw in previous lectures that the minority carrier diffusion length, L_h, is the distance over which minority holes (in this case) diffuse before most recombine. Hence if

$$W_B << L_h = \left(D_h \tau_h\right)^{1/2}$$

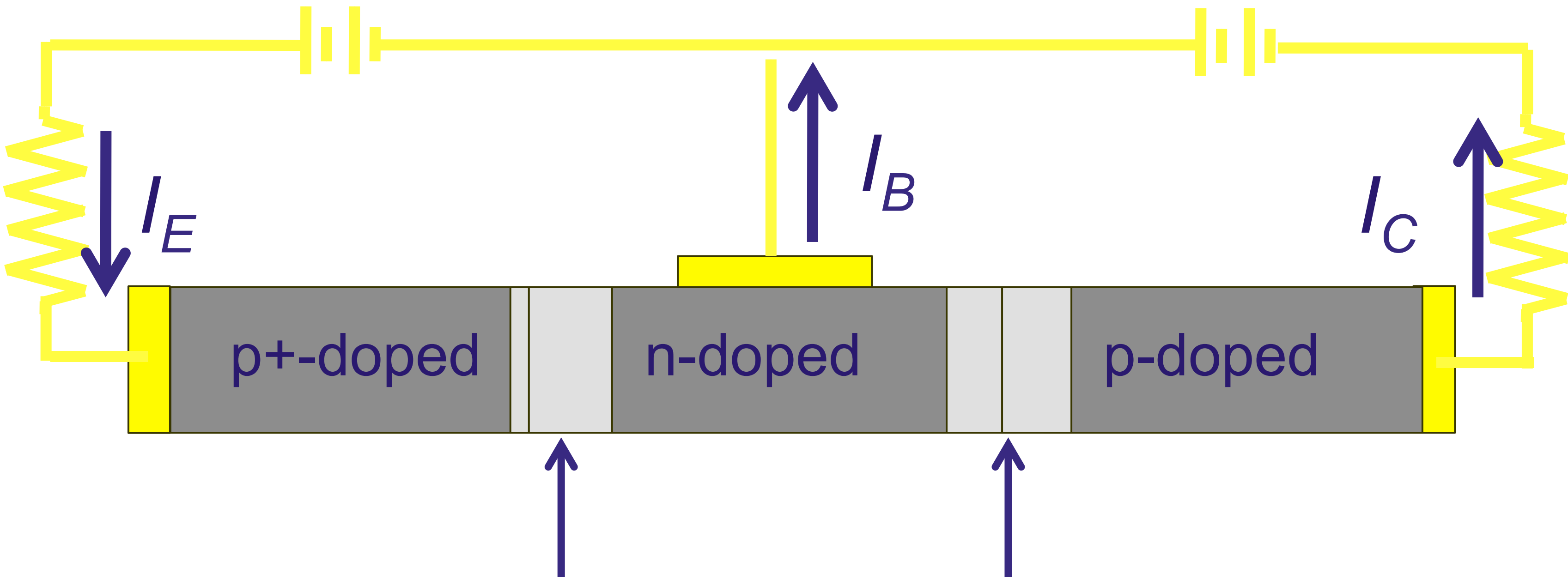
then nearly all holes will reach the collector before they can recombine with electrons in the base.

High Gain BT when $W_b \ll L_h$



When $W_b<<L_h$ nearly all the holes injected into the base reach the base-collector depletion region where they are pulled in by the electric field there and appear as collector current.

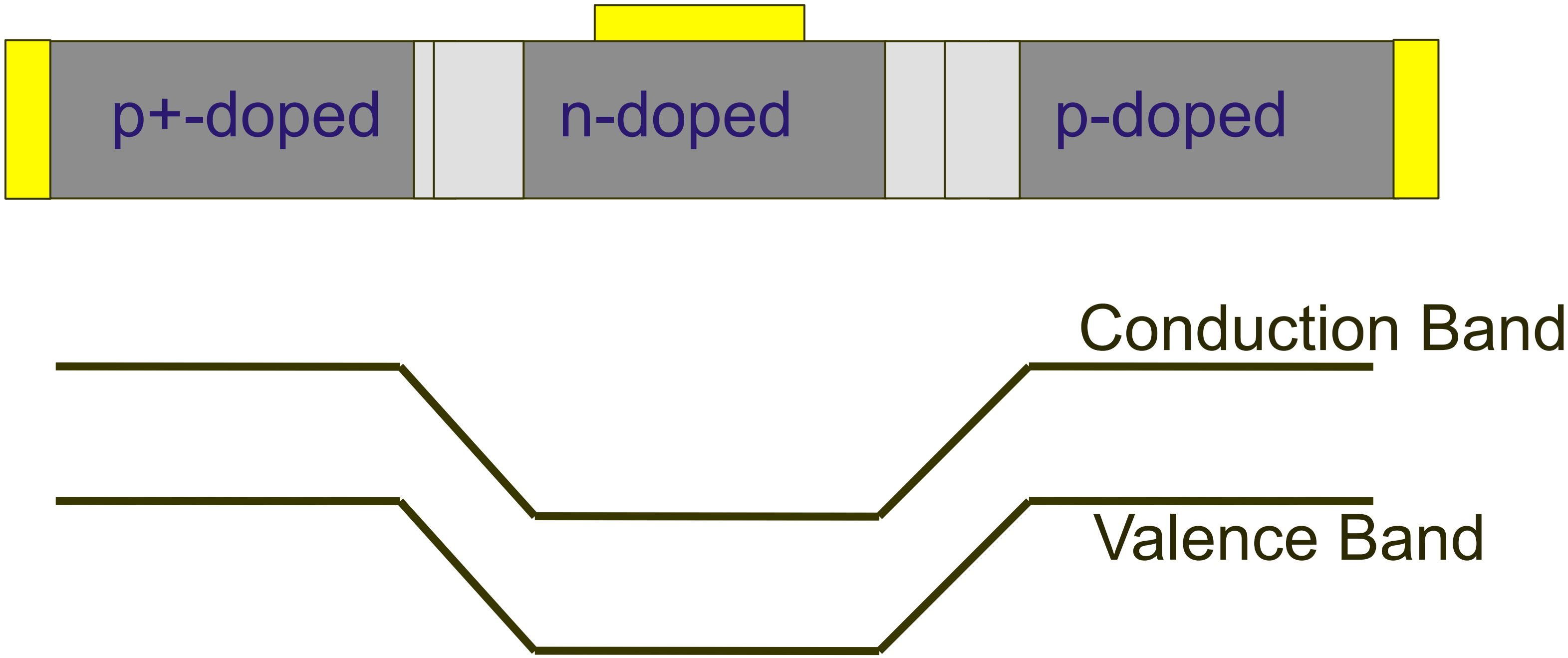
Bias



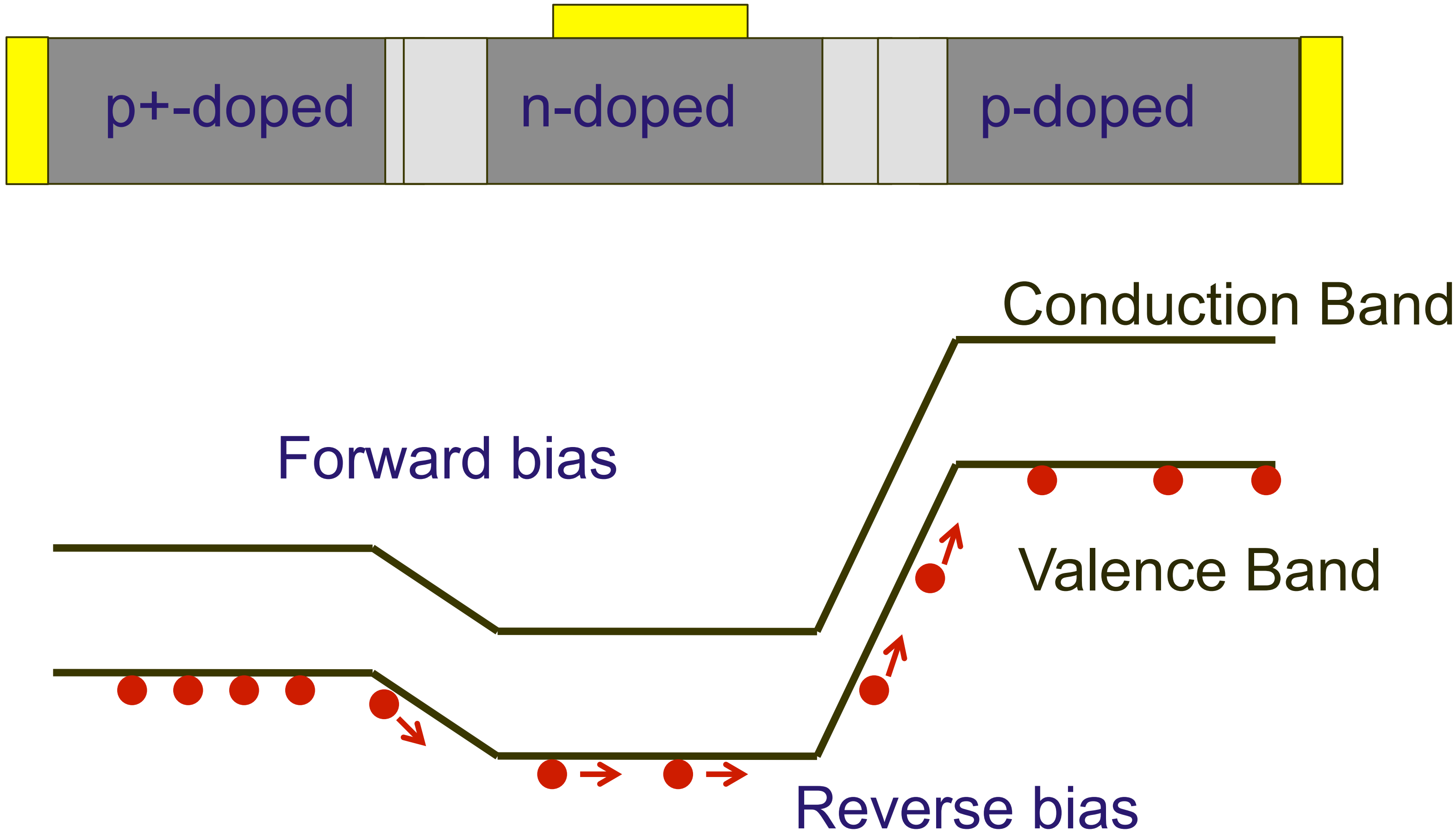
E-B forward biased diode – hole injector since p-doping >> n-doping.

B-C reverse biased – small current unless holes make it to the B-C depletion region.

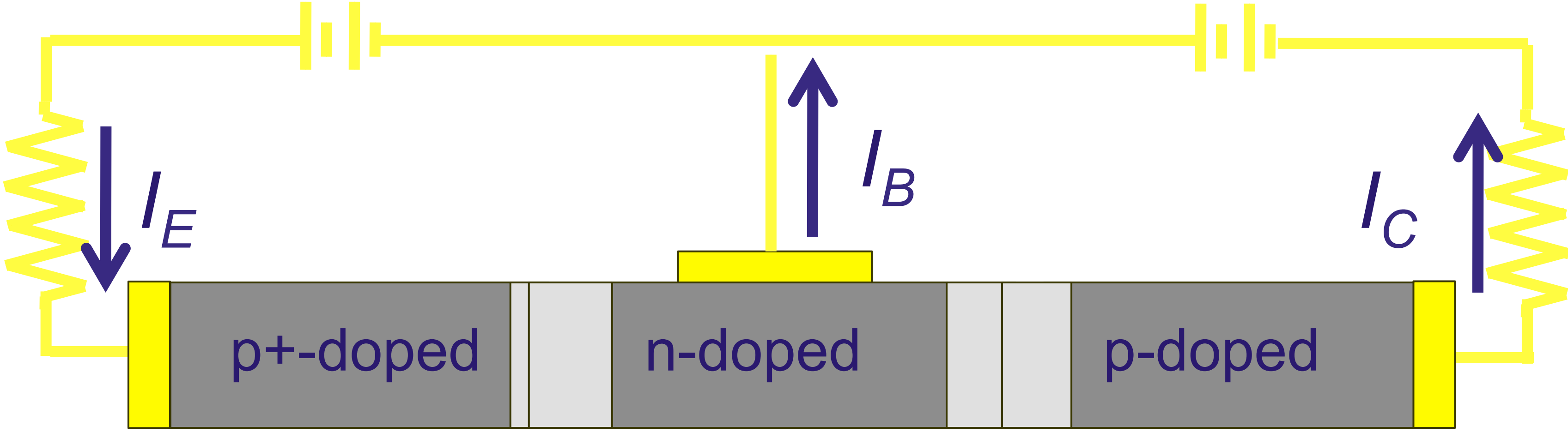
Band diagram - Zero Bias – p+-n-p



Operational Bias – p+-n-p

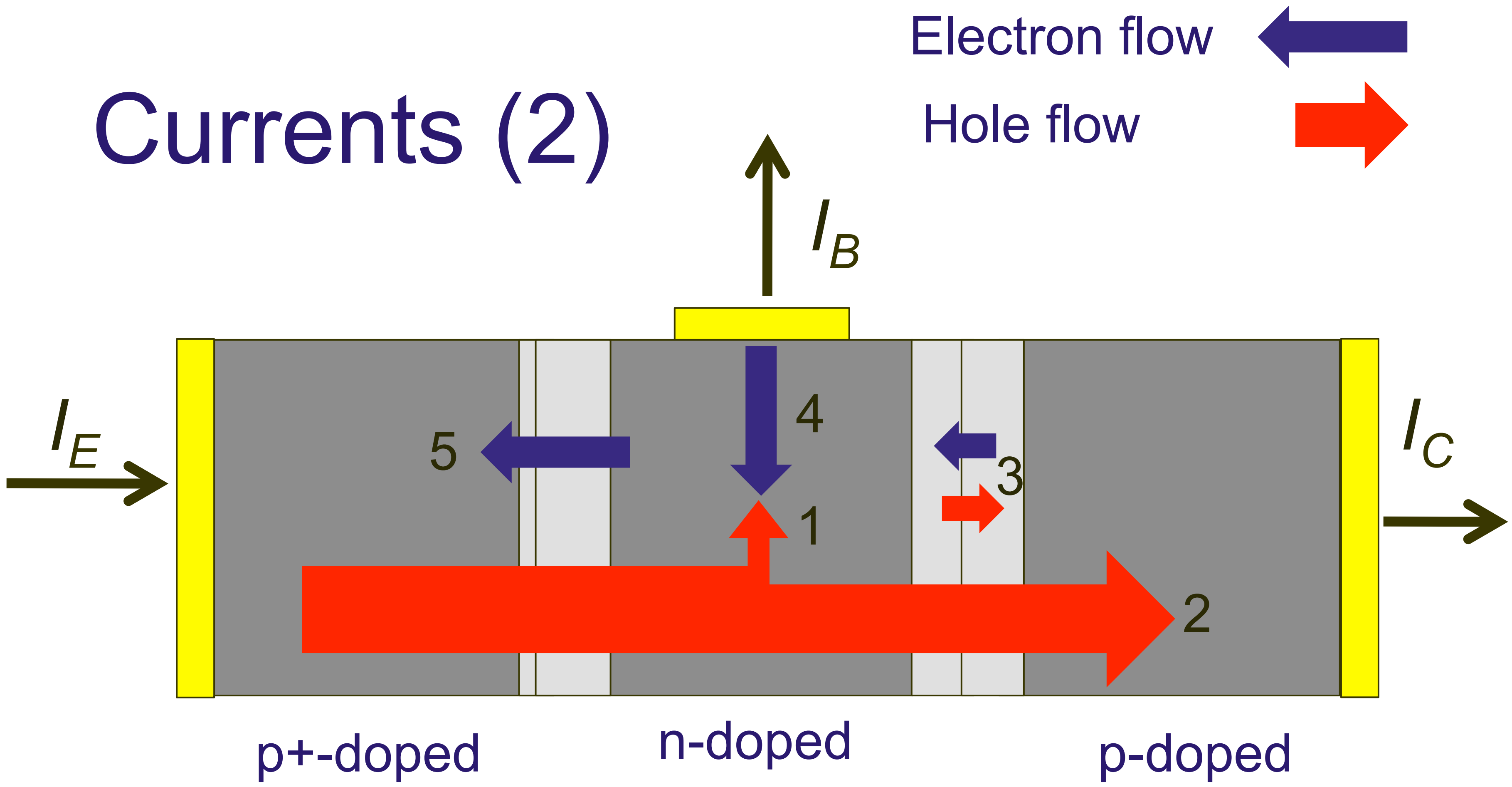


Currents



- For a high-gain transistor $I_E \approx I_C$ and $I_B \approx 0$
- If all the current through the emitter-base is hole current and the base width is small there is no or very little recombination in the base

Currents (2)



Currents (3)

(1) Injected holes lost to recombination in n-type base

(2) Injected holes which reach the reverse biased collector junction

(3) Thermally generated electrons and holes (small - saturation current for this junction)

(4) Electrons supplied to replace those lost by recombination with holes in the base

(5) Electrons injected across the forward biased emitter junction (small)

Summary

- The small and constant reverse current in the B-C junction is due to the thermal generation of minority carriers in or near the depletion region
- The B-C current can be enhanced with hole injection from the forward bised E-B junction
- A thin base is required to ensure nearly all the minority carriers injected by the emitter arrive at the collector
- Other smaller currents are also present