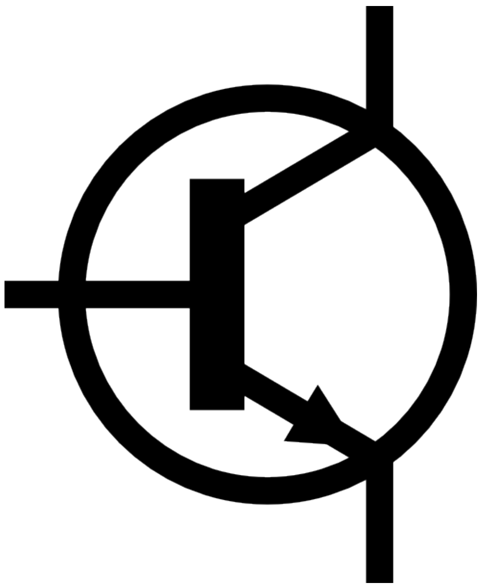
Bipolar Junction Transistor



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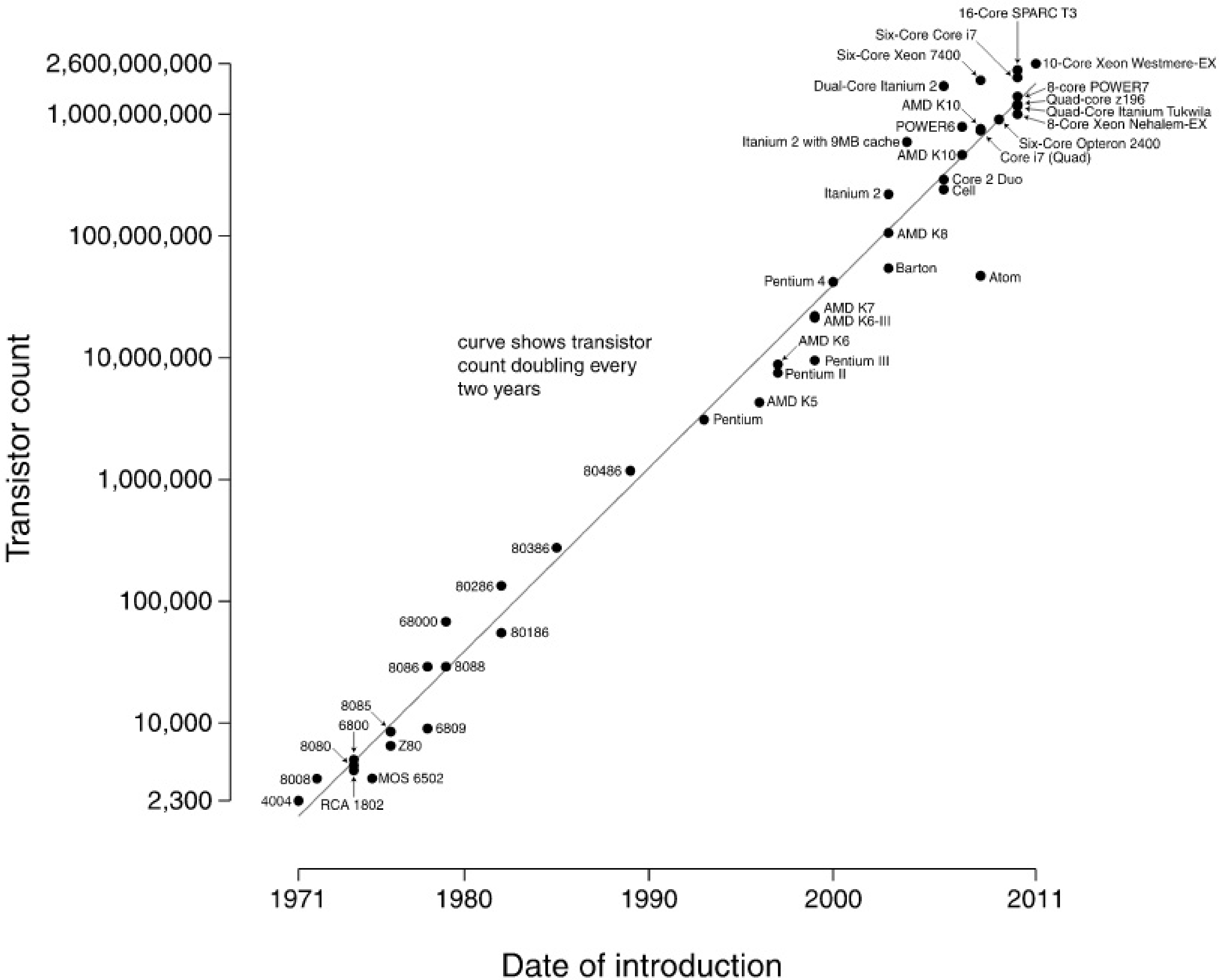
What is a transistor?

- Device used to amplify or switch signals
- Computer processors
- Progress
  - Vacuum tubes, early field effect transistors, BJT
- Moore’s Law

Microprocessor Transistor Counts 1971-2011 & Moore's Law



Overview

- Inventors (1956 Nobel Prize)
- History
- Physics
- Modes of Operation

Inventors

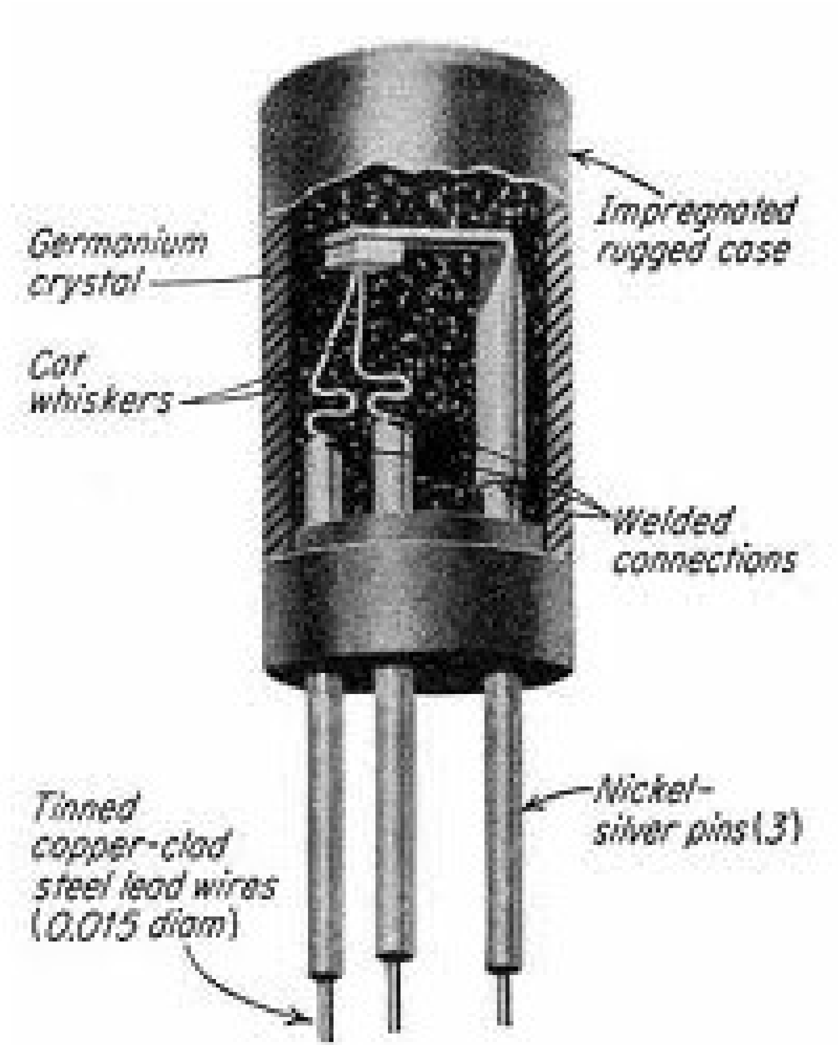
John Bardeen

Walter Brattain

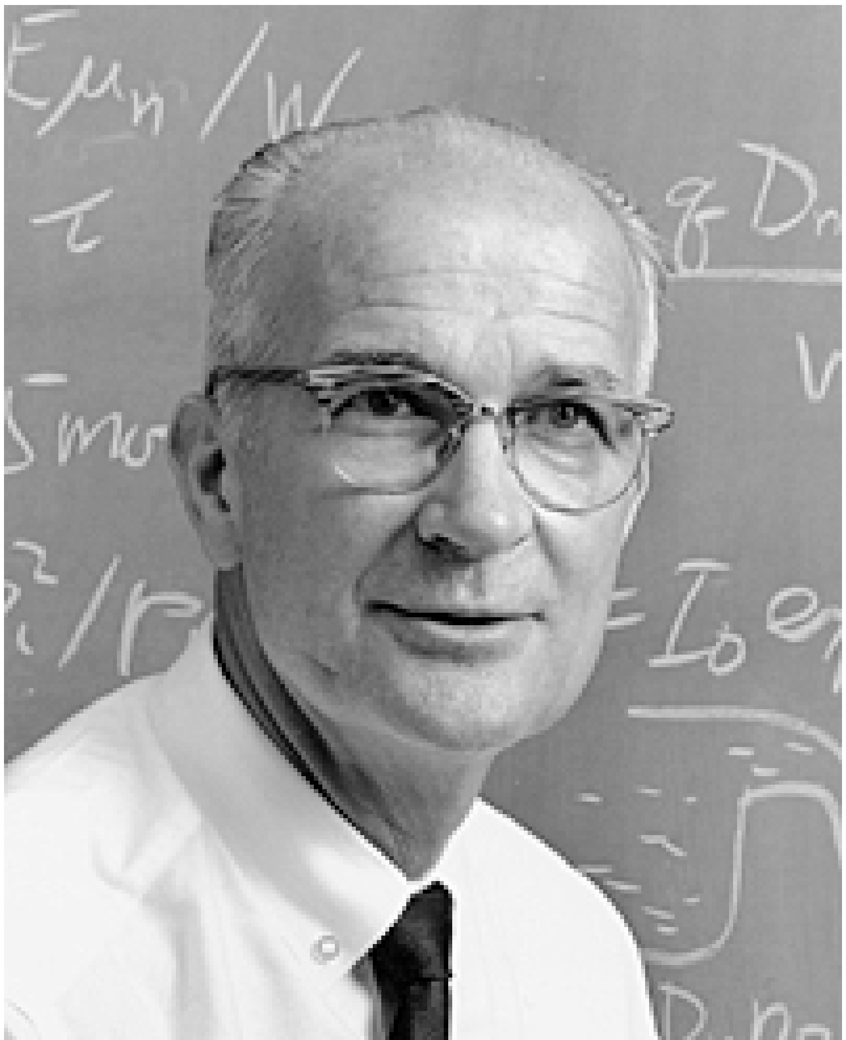
Inventors

- John Bardeen and Walter Brattain
  - Employees of Bell Laboratories
  - Worked under William Shockley (3rd inventor)
  - Did much of the work
- Afterward
  - Shockley claimed most of the credit
  - Strained relationship
  - Bardeen won a 2nd Nobel Prize for BCS theory of superconductivity (1972)

Point Contact Transistor



Inventors



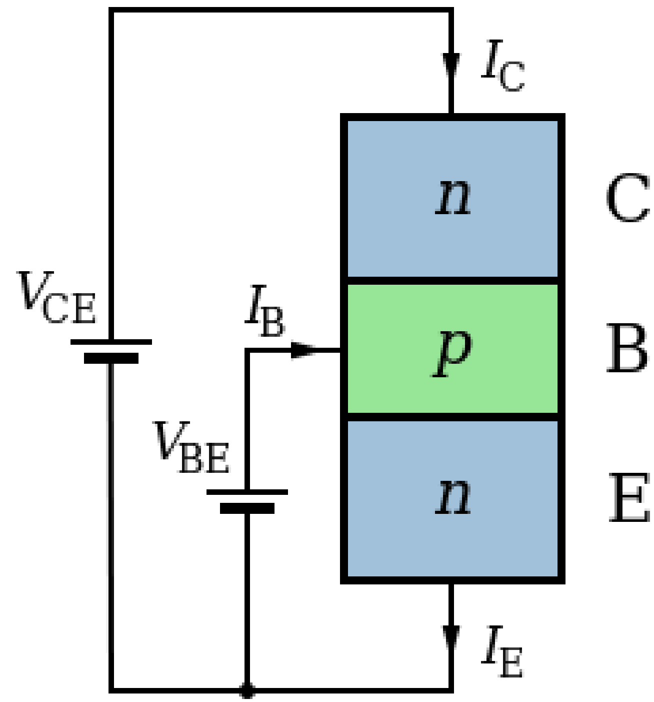
- William Shockley
  - Worked in secret on better transistor design
  - Major contributions to semiconductor physics
- Racist
  - Public proponent of eugenics

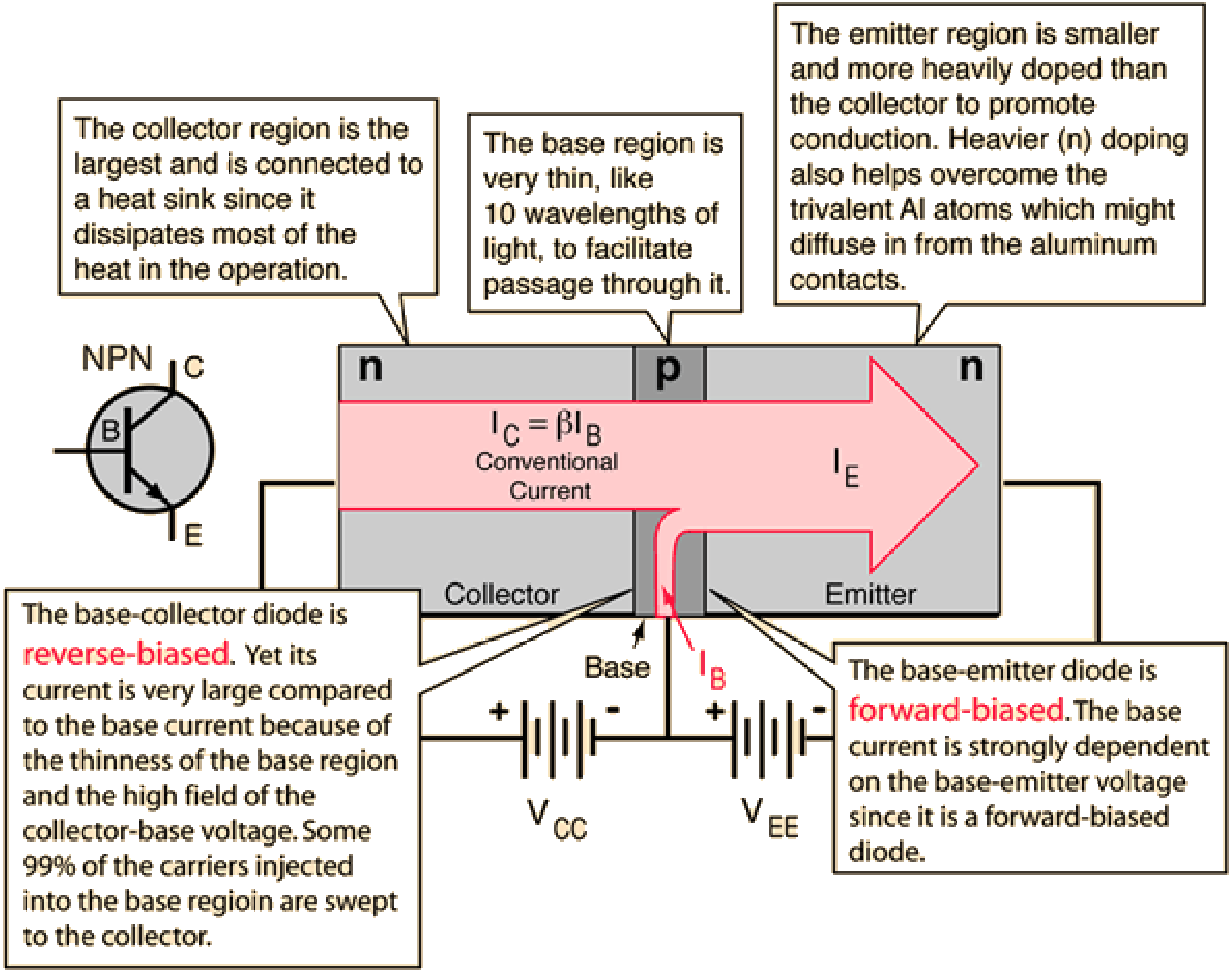
History

- Bell Labs wanted to create a solid state triode
  - Faster switching time
  - Cheaper
  - More reliable
  - No need to warm up
- Surface physics
  - Charge carrier behavior
  - Bardeen established this new subject

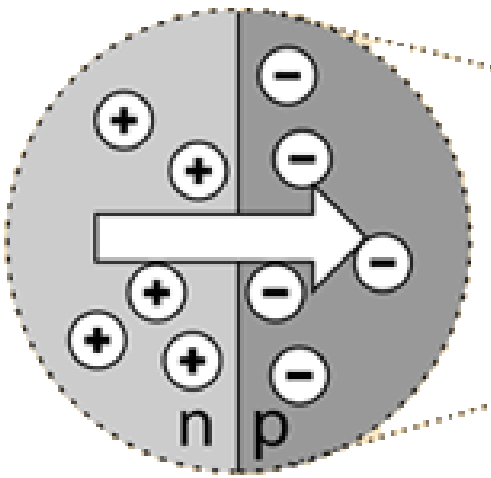
Physics

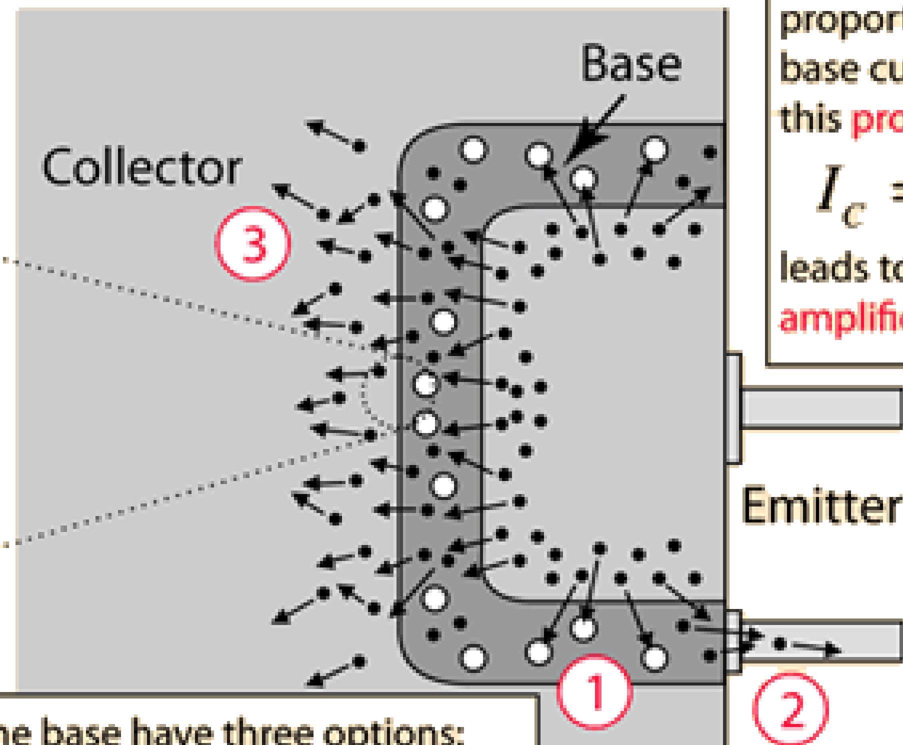
- Simplest picture
  - Two p-n diodes joined together
  - Flow of electrons and holes depends on doping and bias
  - E: Emitter
  - B: Base
  - C: Collector
  - $I_C = \beta I_B$
  - β typically ~200




The collector region is the largest and is connected to a heat sink since it dissipates most of the heat in the operation.
The base region is very thin, like 10 wavelengths of light, to facilitate passage through it.
The emitter region is smaller and more heavily doped than the collector to promote conduction. Heavier (n) doping also helps overcome the trivalent Al atoms which might diffuse in from the aluminum contacts.
NPN
C
B
E
n
p
n
$I_C = \beta I_B$
Conventional Current
I_E
Collector
Emitter
Base
I_B
+
-
+
-
V_{CC}
V_{EE}
The base-collector diode is reverse-biased. Yet its current is very large compared to the base current because of the thinness of the base region and the high field of the collector-base voltage. Some 99% of the carriers injected into the base regioin are swept to the collector.
The base-emitter diode is forward-biased. The base current is strongly dependent on the base-emitter voltage since it is a forward-biased diode.

There is a large electric field across the collector-base junction in the depletion zone caused by the reverse bias.





The collector current in a transistor is proportional to the base current, and this proportionality

$$I_C = \beta I_B$$

leads to current amplification.

Electrons moving from the emitter to the base have three options:

1. Combine with holes in the base. Holes are the majority carriers in the p-type material.
2. Diffuse through the base and out the base connection.
3. Diffuse across the base region into the depletion layer of the collector-base junction where they are swept by the electric field into the collector.

About 99% of the conduction is by process 3!!

Amplification

- The current in the base is given by

$$I_B = \frac{qD_n n_{pE0} A_E}{W_B}(e^{V_{BE}/v_{th}})$$

Where q is charge, D_n is diffusivity of electrons, n_{pE0} is density of holes, A_E is area, W_B is width, V_{BE} is the potential across the base-emitter junction, and v_{th} is thermal speed.

- Similarly, current in the emitter is given by

$$I_E \approx \frac{qD_p p_{nE0} A_E}{W_E}(e^{V_{BE}/v_{th}})$$

- Also, $I_C \approx I_E$
- So that $$\beta_F \approx \frac{D_n N_{dE} W_E}{D_p N_{aB} W_B}$$

Where N represents dopant concentration. For typical values of these parameters, β is around 200 but varies with use because of implicit dependence on temperature and bias.

Modes of Operation

- Forward Active Region
  - BE forward biased, BC reverse biased

- Reverse Active Region
  - BE reverse biased, BC forward biased

- Saturation
  - Both forward biased
  - “On”

- Cutoff
  - Both reverse biased
  - “Off”

References

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