EE 434
Lecture 19

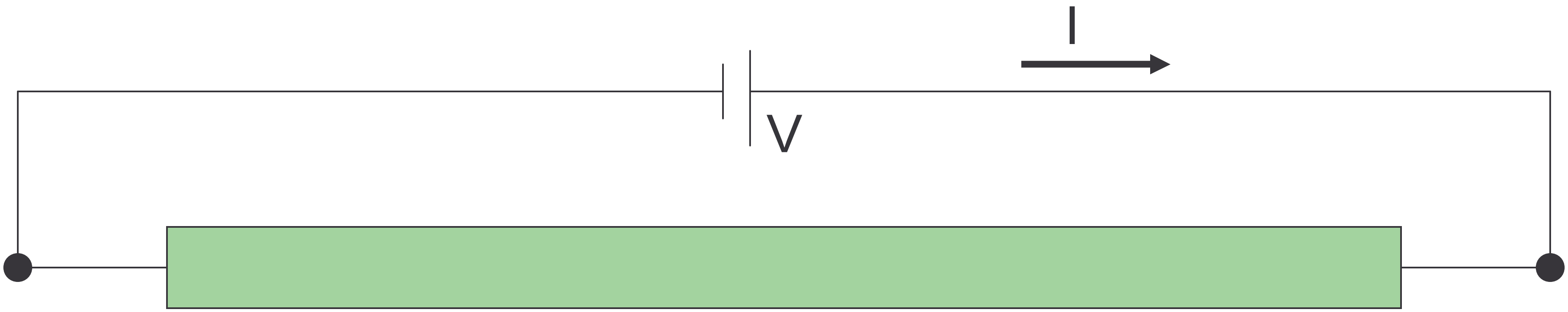
Bipolar Devices

Carriers in Doped Semiconductors

n-type

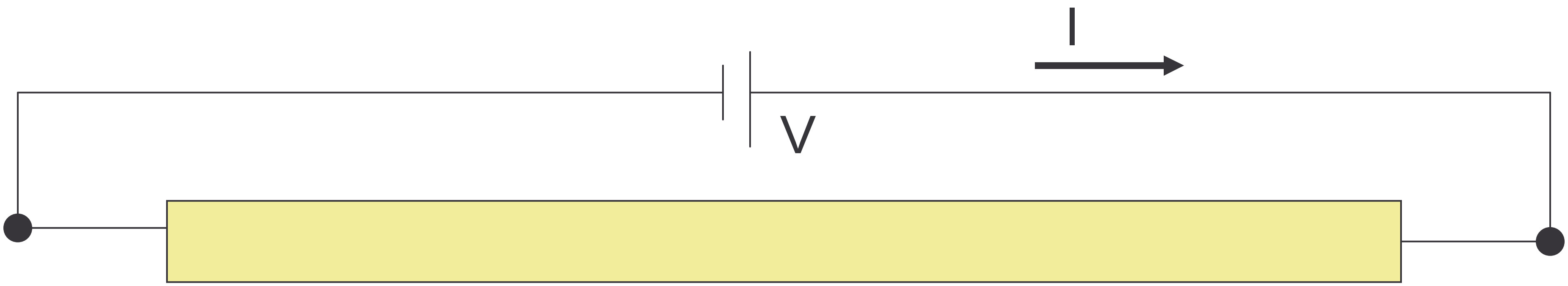
p-type

Carriers in Doped Semiconductors



Current carriers are dominantly electrons

Small number of holes are short-term carriers



Current carriers are dominantly holes

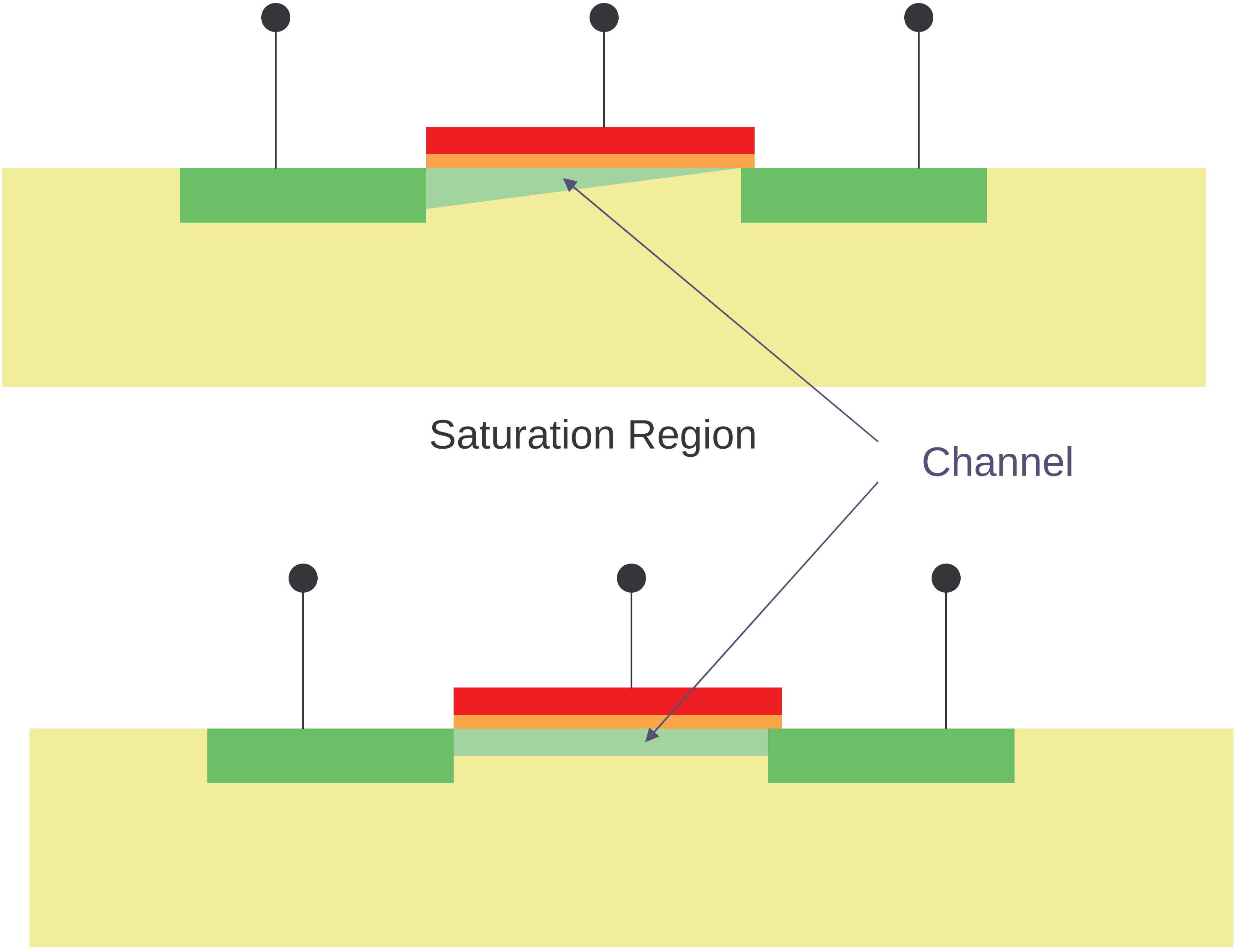
Small number of electrons are short-term carriers

Carriers in Doped Semiconductors

	Majority Carriers	Minority Carriers
n-type	electrons	holes
p-type	holes	electrons

Carriers in MOS Transistors

Consider n-channel MOSFET

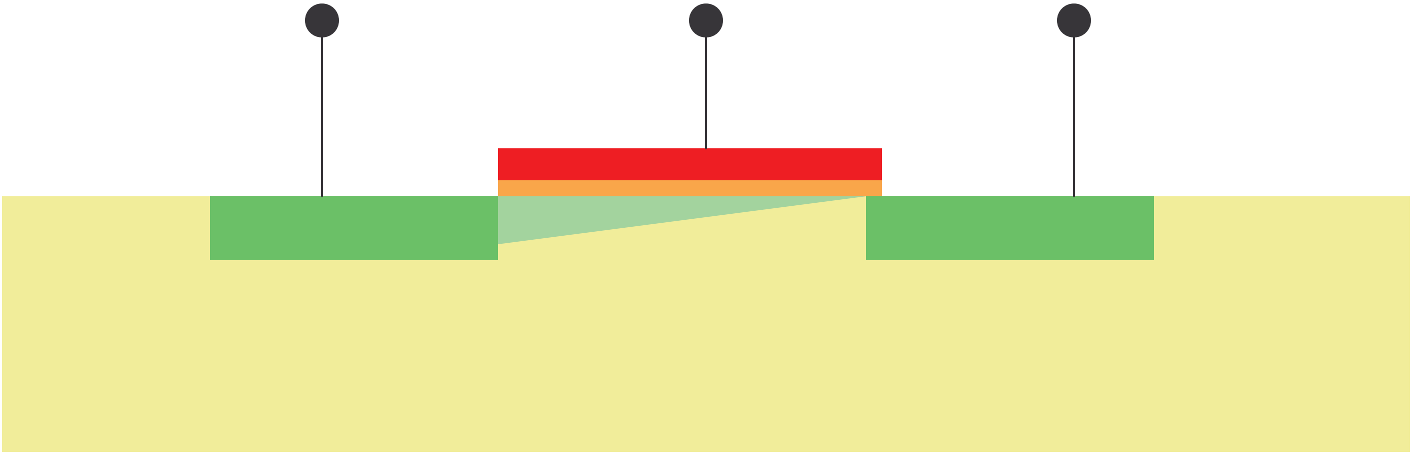


Saturation Region

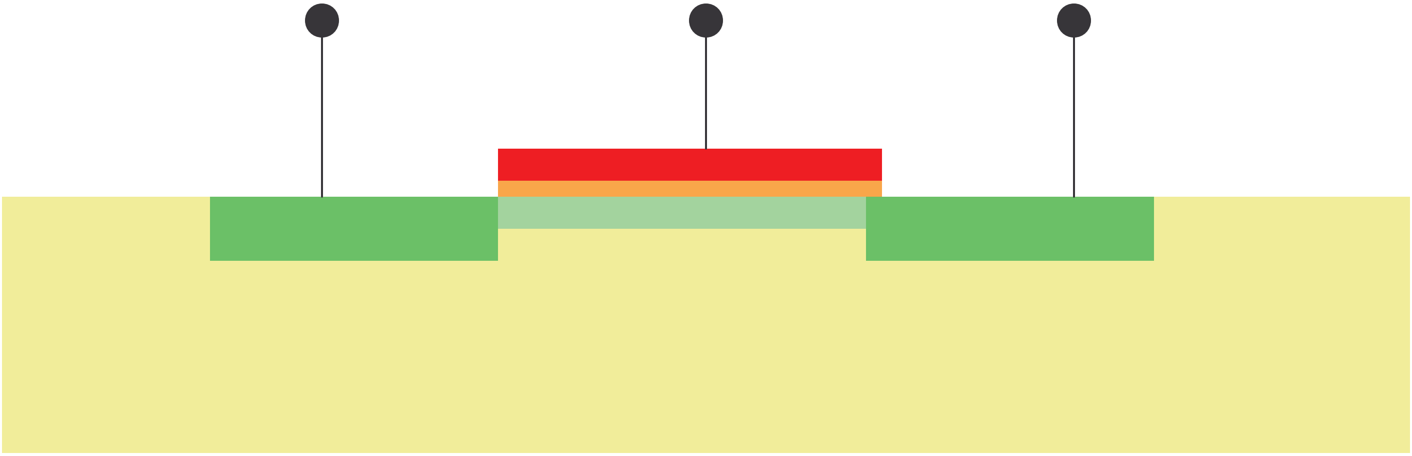
Triode Region

Carriers in MOS Transistors

Consider n-channel MOSFET



Saturation Region

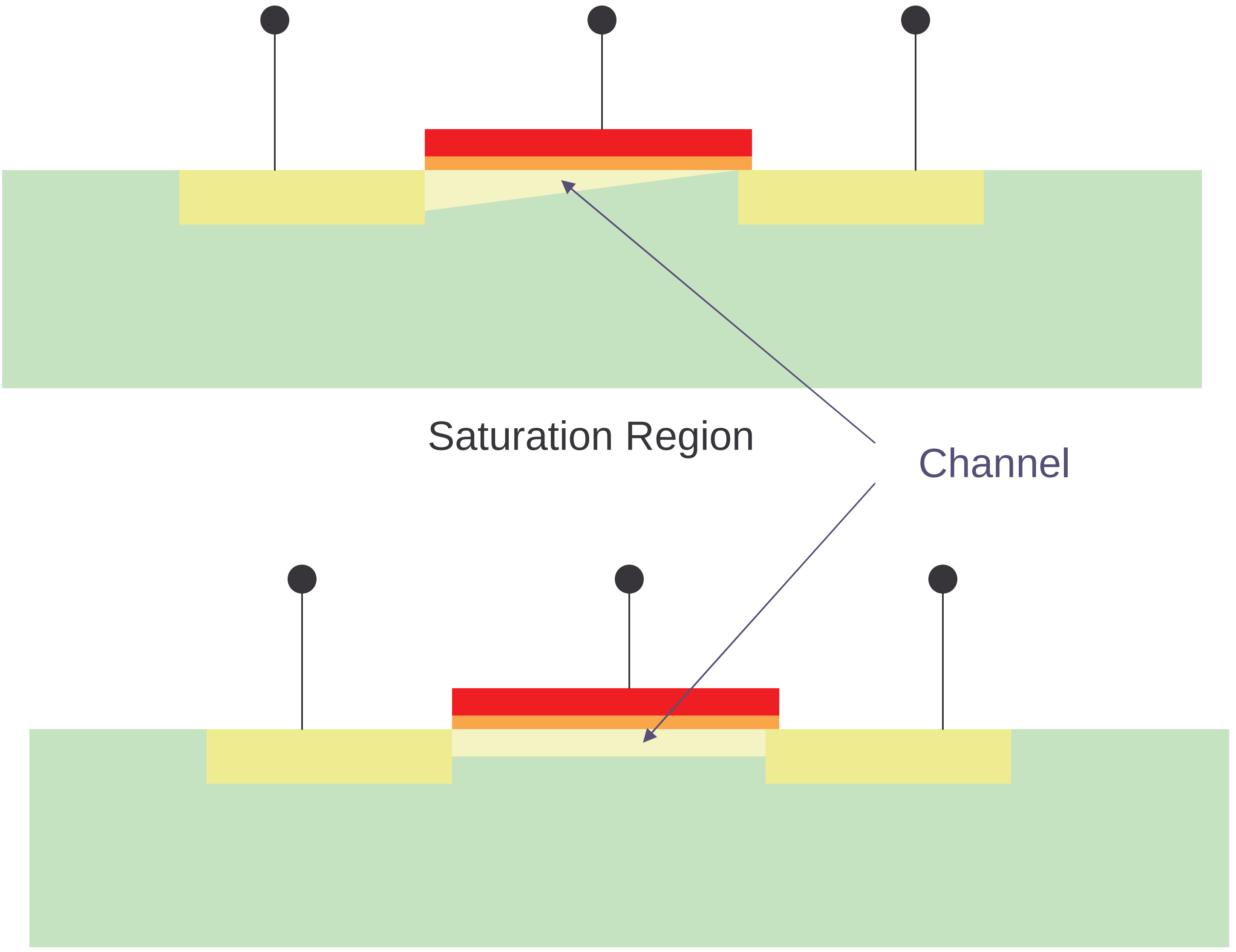


Triode Region

Carriers in electrically induced n-channel are electrons

Carriers in MOS Transistors

Consider p-channel MOSFET



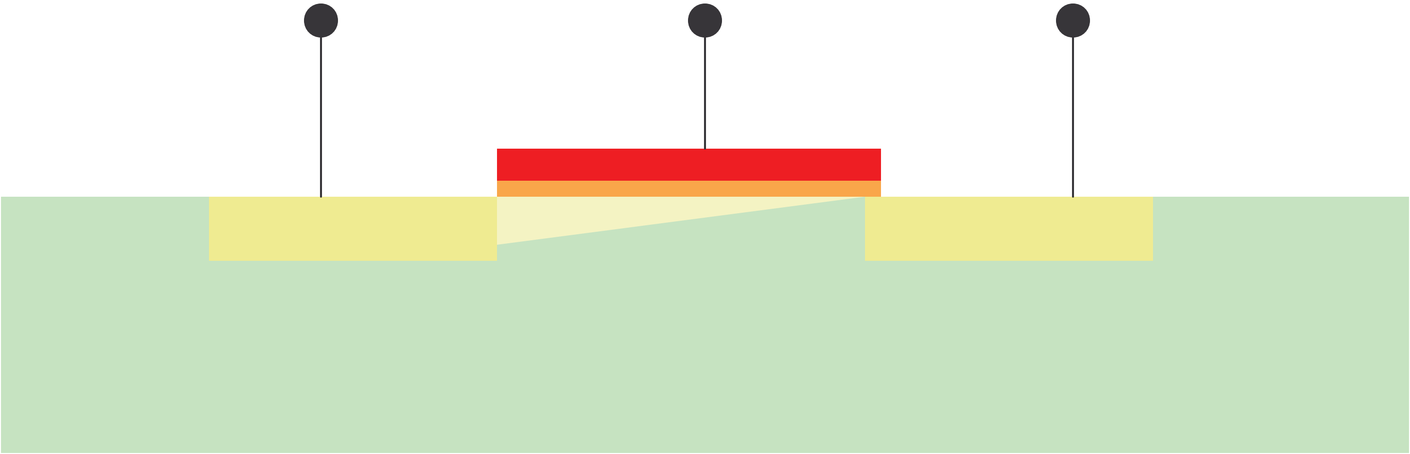
Saturation Region

Channel

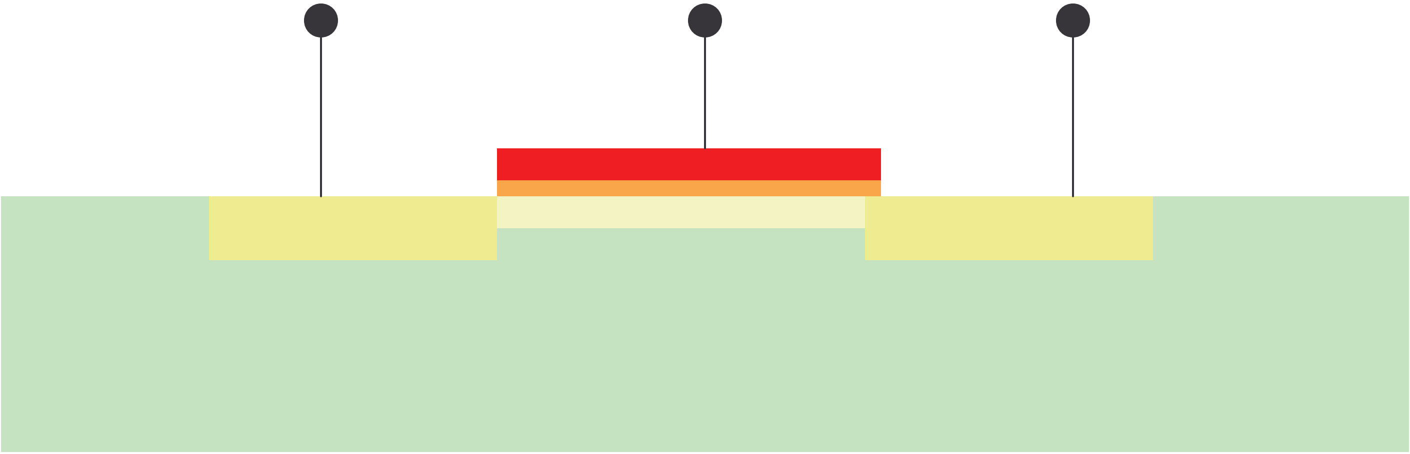
Triode Region

Carriers in MOS Transistors

Consider p-channel MOSFET



Saturation Region



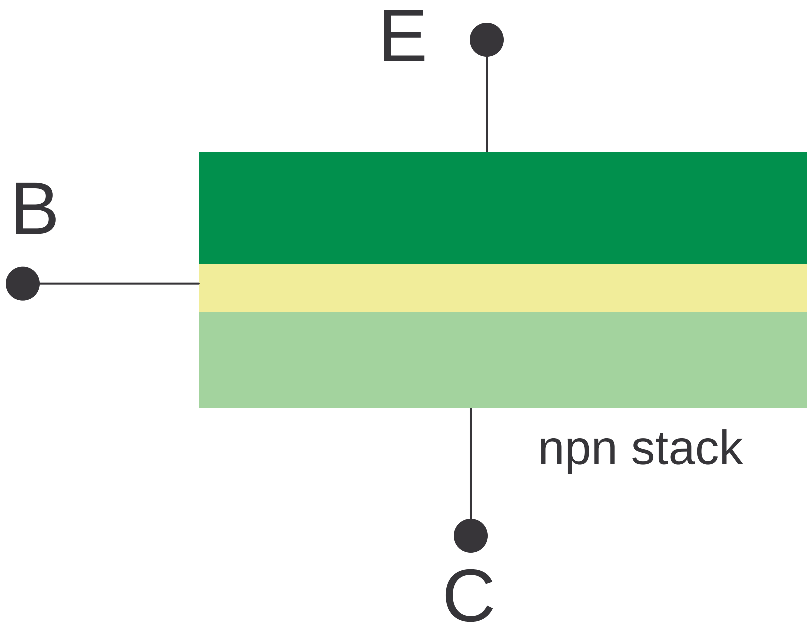
Triode Region

Carriers in electrically induced p-channel are holes

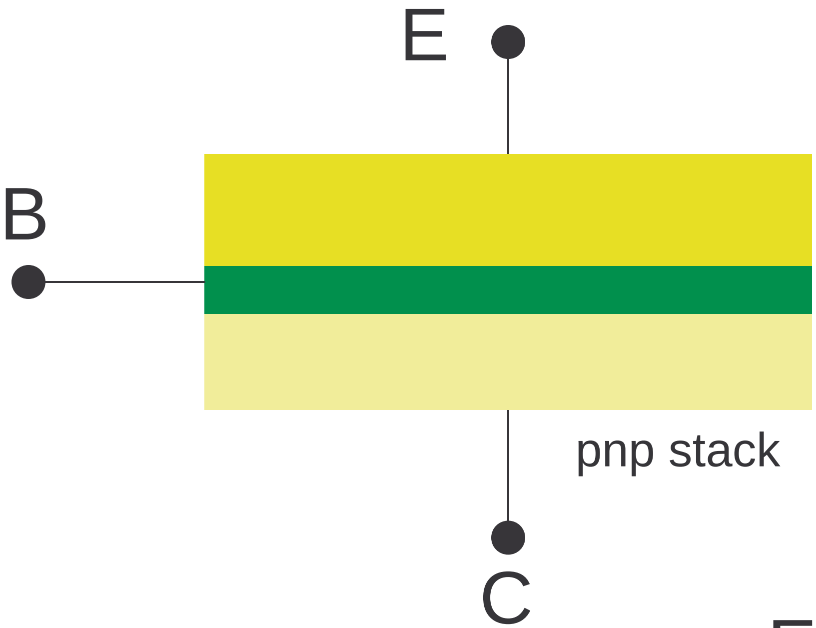
Carriers in MOS Transistors

Carriers in channel of MOS transistors are Majority carriers

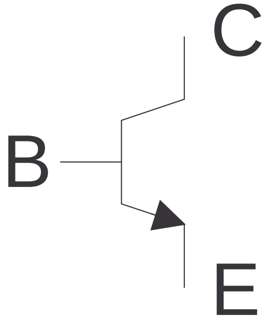
Bipolar Transistors



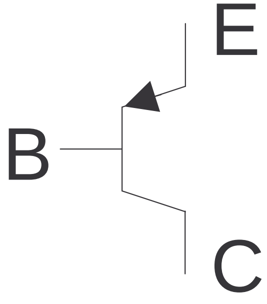
npn stack



pnp stack



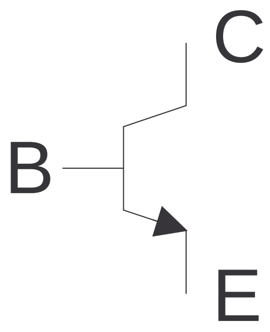
npn transistor



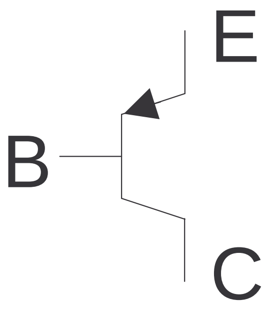
pnp transistor

With proper doping and device sizing these form Bipolar Transistors

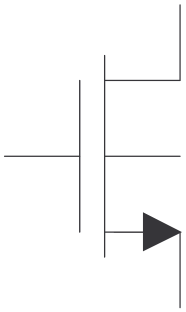
Bipolar Transistors



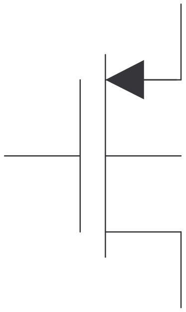
npn transistor



pnp transistor



n-channel MOSFET

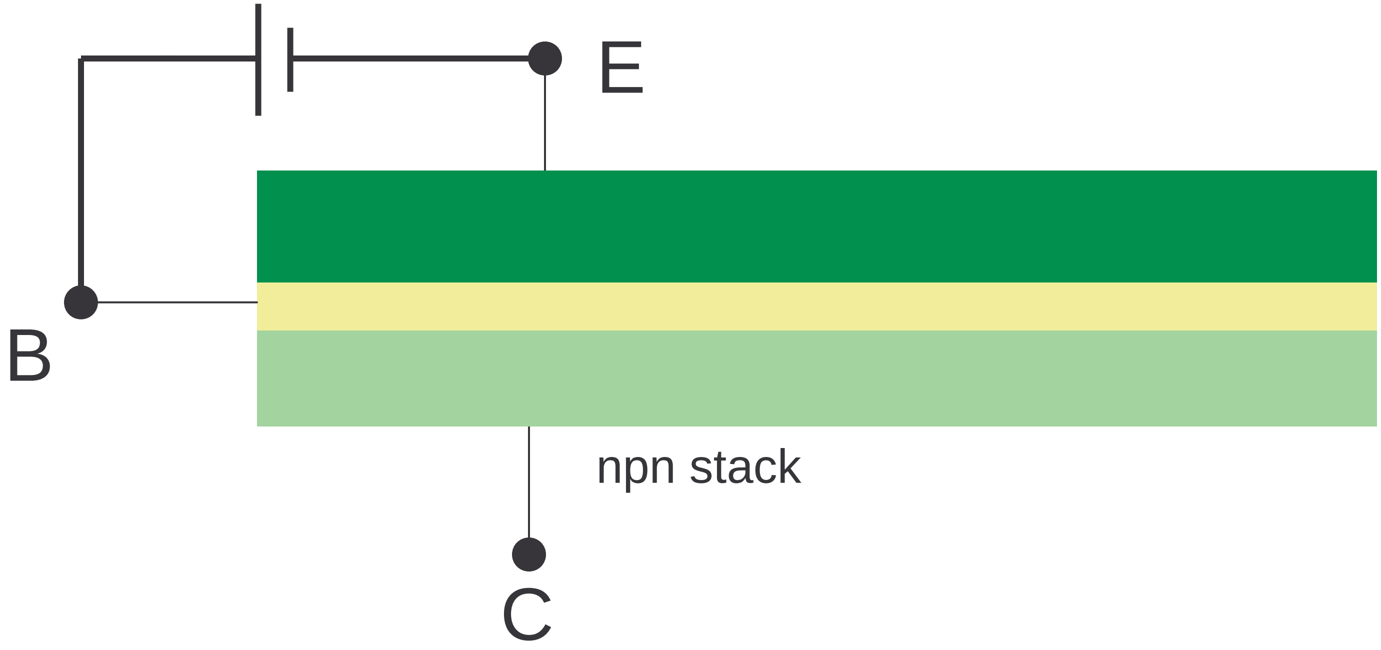


p-channel MOSFET

In contrast to a MOSFET which has 4 terminals, a BJT only has 3 terminals

Bipolar Operation

Consider npn transistor



Under **<u>forward bias</u>** current flow into base and out of emitter

Current flow is governed by the diode equation

Carriers in emitter are electrons (majority carriers)

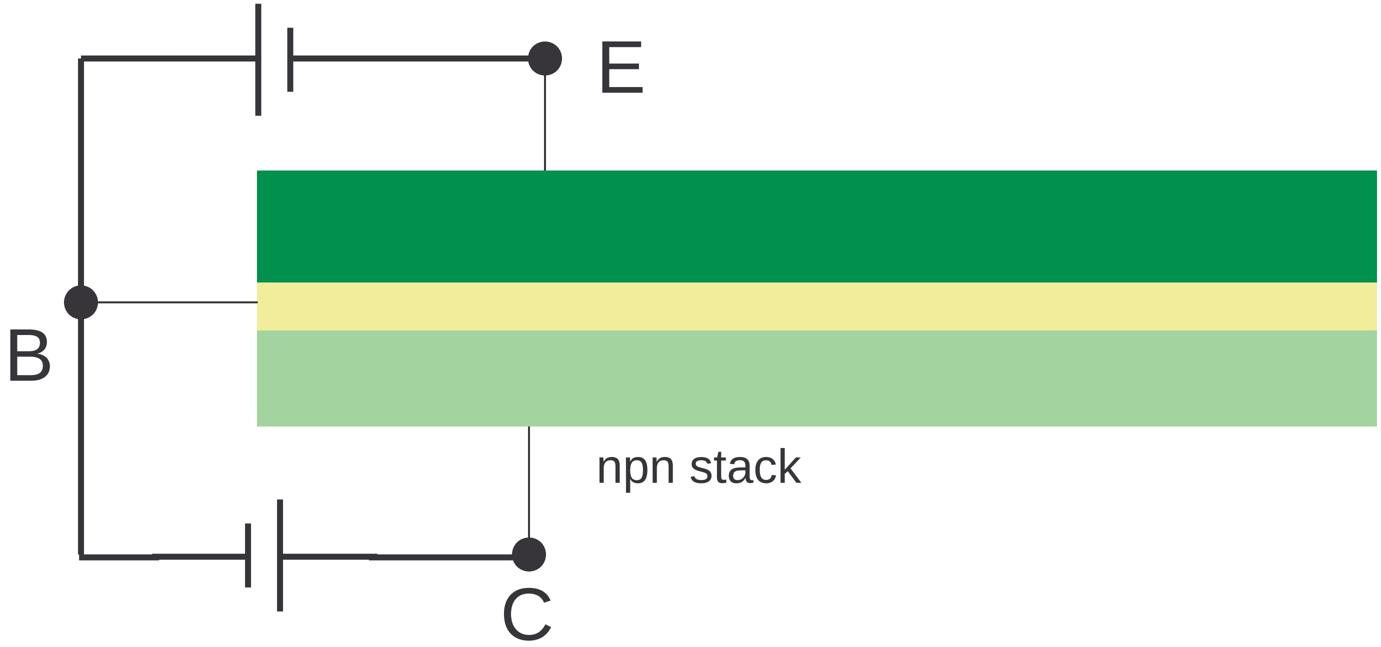
When electrons pass into the base they become minority carriers

Quickly recombine with holes to create holes base region

Dominant current flow in base is holes (majority carriers)

Bipolar Operation

Consider npn transistor



Under forward BE bias and reverse BC bias current flows into base **region**

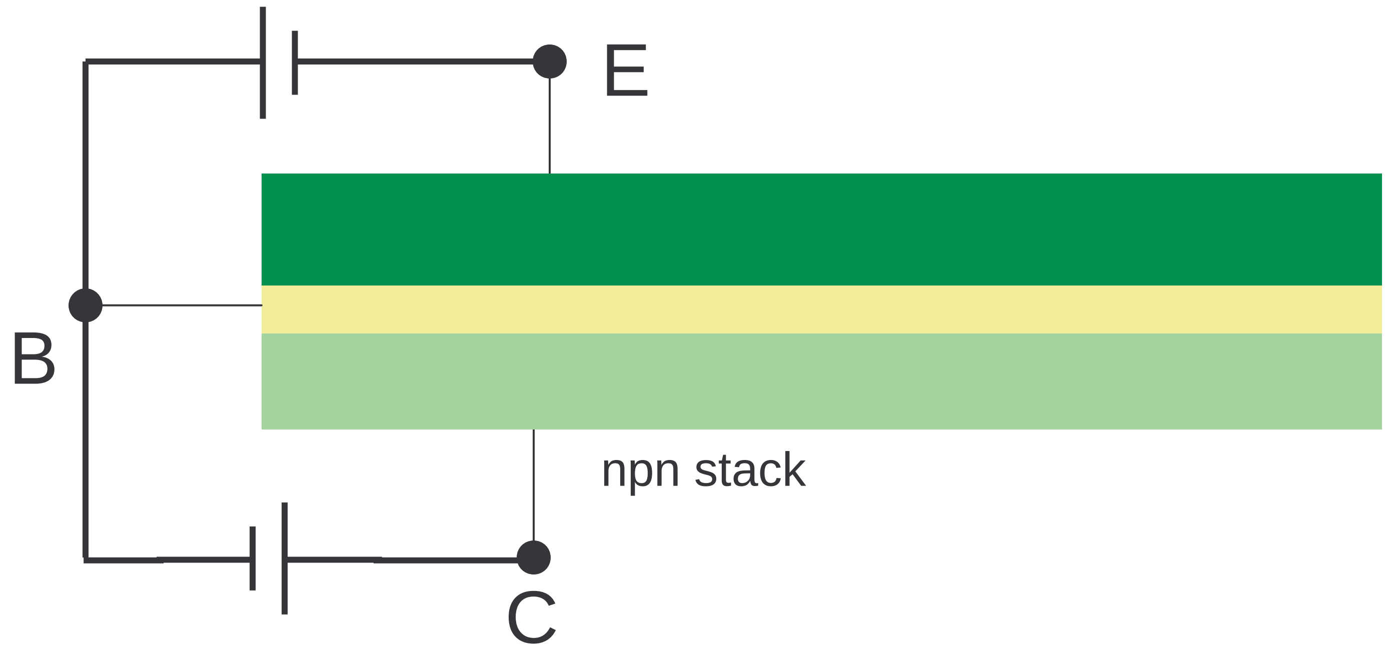
Carriers in emitter are electrons (majority carriers)

When electrons pass into the base they become minority carriers

When minority carriers are present in the base they can be attracted to collector
Minority carriers either recombine with holes and contribute to base current
or are attracted into collector region and contribute to collector current

Bipolar Operation

Consider npn transistor



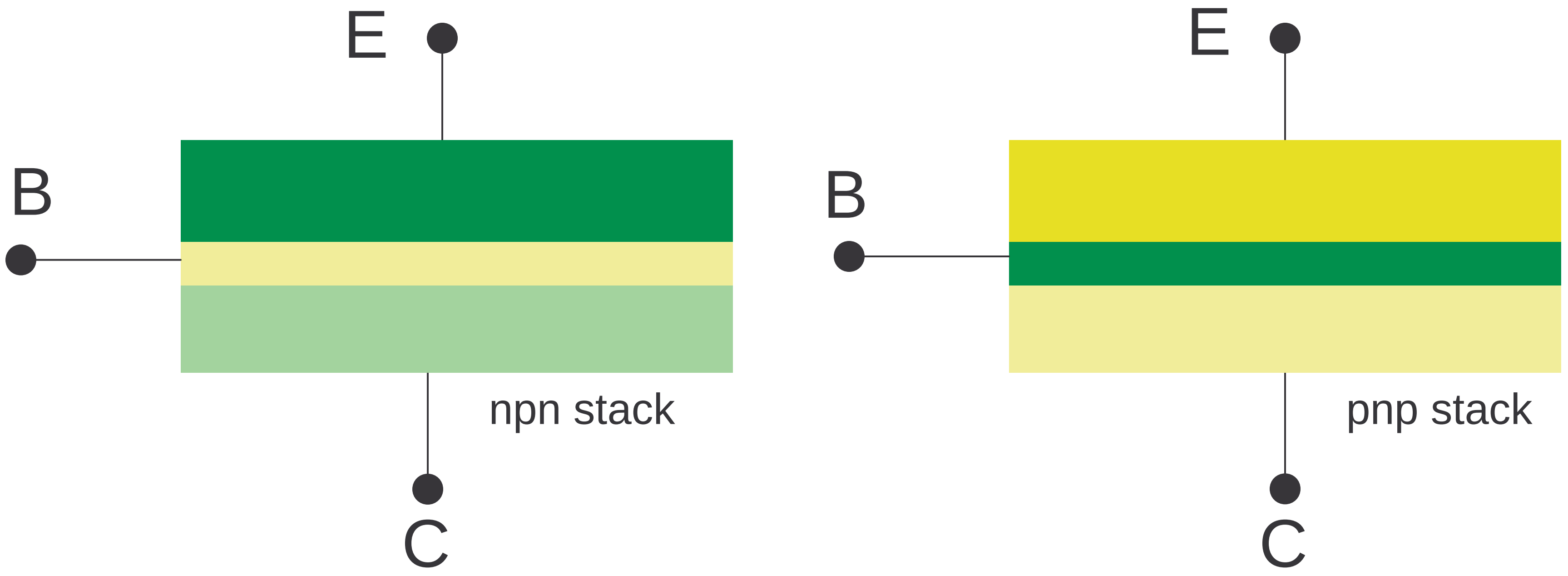
Under forward BE bias and reverse BC bias current flows into base **region**

Efficiency at which minority carriers injected into base region and contribute to collector current is termed α

α is always less than 1 but for a good transistor, it is very close to 1

For good transistors .99 < α < .999
Making the base region very thin makes α large

Bipolar Transistors



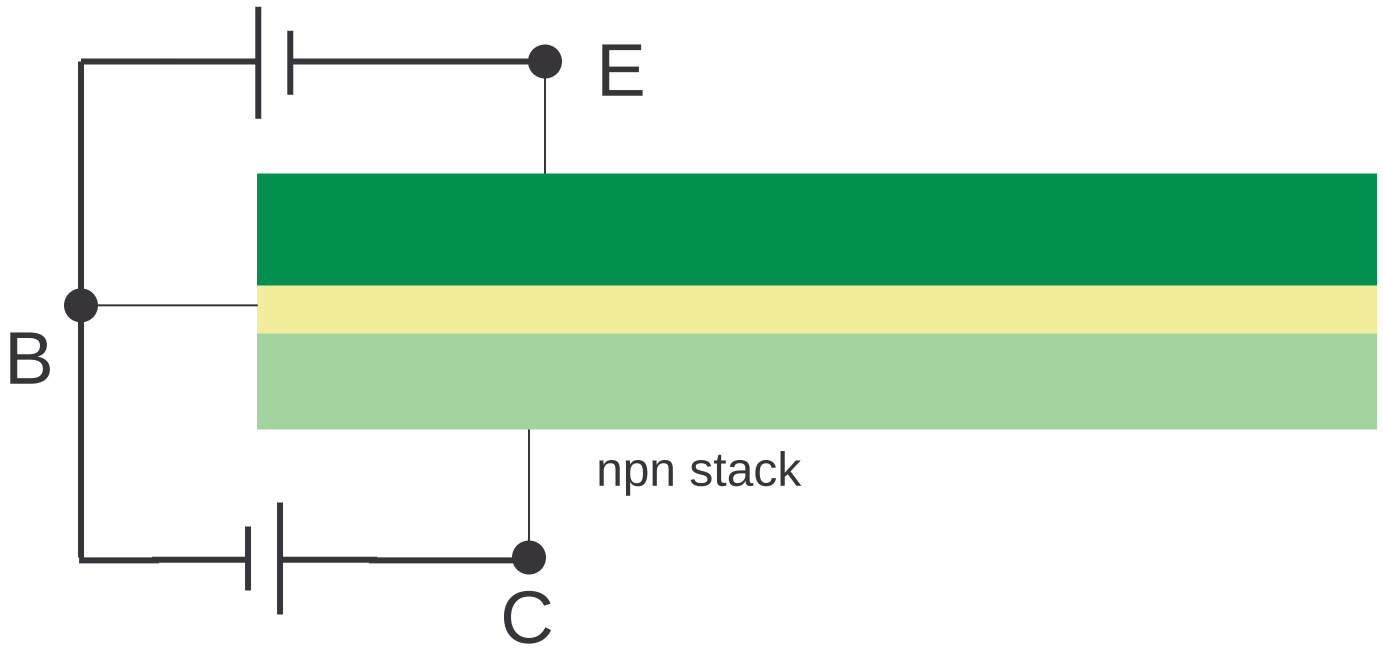
principle of operation of pnp and npn transistors are the same

minority carriers in base of pnp are holes

npn usually have modestly superior properties because mobility of electrons
Is larger than mobility of holes

Bipolar Operation

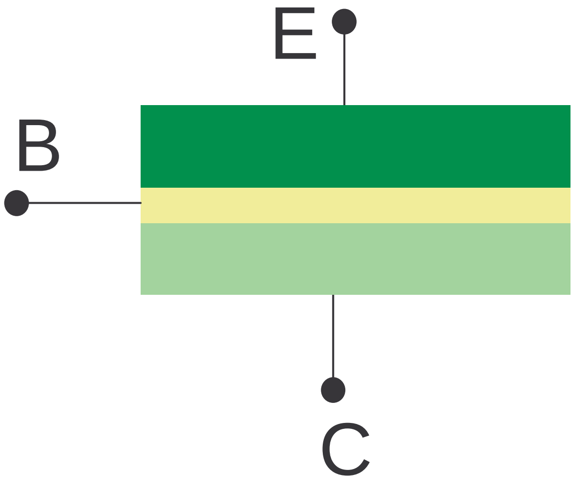
Consider npn transistor

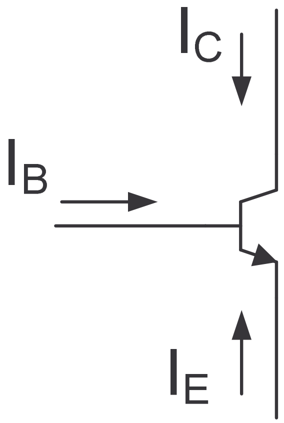


In contrast to MOS devices where current flow in channel is by majority carriers, current flow in the critical base region of bipolar transistors is by minority carriers

$I_C = \beta I_B$

Bipolar Operation





$$\left.\begin{aligned} I_C + I_B &= -I_E \\ I_C &= -\alpha I_E \end{aligned}\right\}$$

$$I_C = \frac{\alpha}{1-\alpha} I_B$$

$$\beta \overset{defn}{=} \frac{\alpha}{1-\alpha}$$

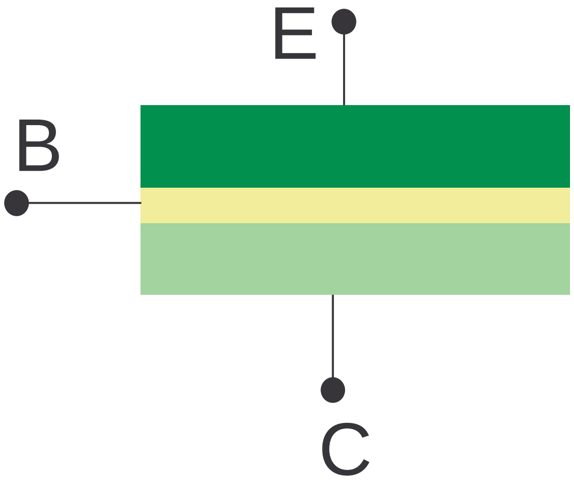
$$I_C = \beta I_B$$

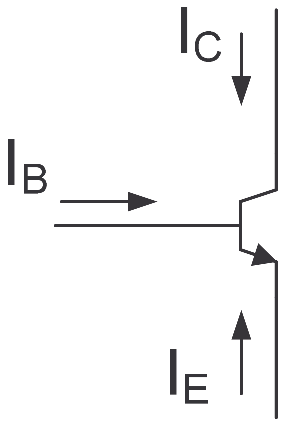
β is typically very large

often 50<β<999

$I_C = \beta I_B$

Bipolar Operation





$$I_C = \beta I_B$$

β is typically very large

Bipolar transistor can be thought of a current amplifier with a large current gain

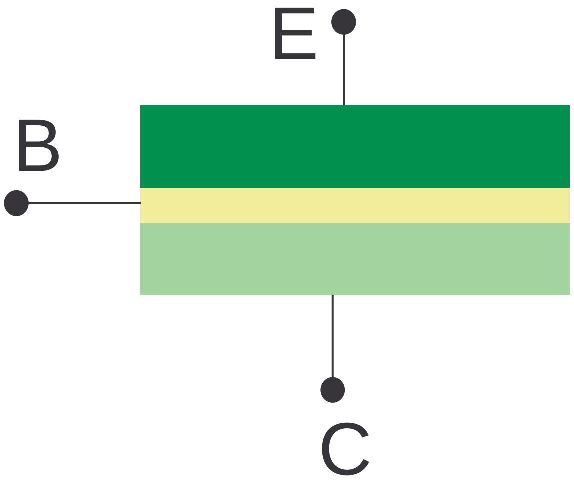
In contrast, MOS transistor is inherently a tramsconductance amplifier

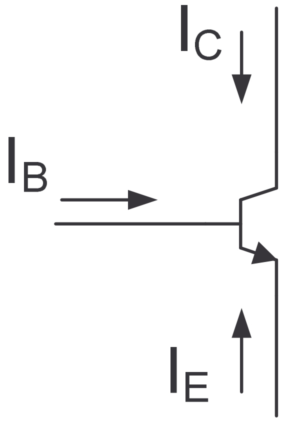
Current flow in base is governed by the diode equation $$I_B = \tilde{I}_S e^{\frac{V_{BE}}{V_t}}$$

Collector current thus varies exponentially with V_{BE} $$I_C = \beta \tilde{I}_S e^{\frac{V_{BE}}{V_t}}$$

$I_C = \beta I_B$

Bipolar Operation





$$I_C = \beta I_B$$

β is typically very large

Collector current thus varies exponentially with V_{BE}

$$I_C = \beta \tilde{I}_S e^{\frac{V_{BE}}{V_t}}$$

This exponential relationship (in contrast to the square-law relationship for the MOSFET) provides a very large gain for the BJT and this property is very useful for many applications !!