Power Converters

Power Transistors

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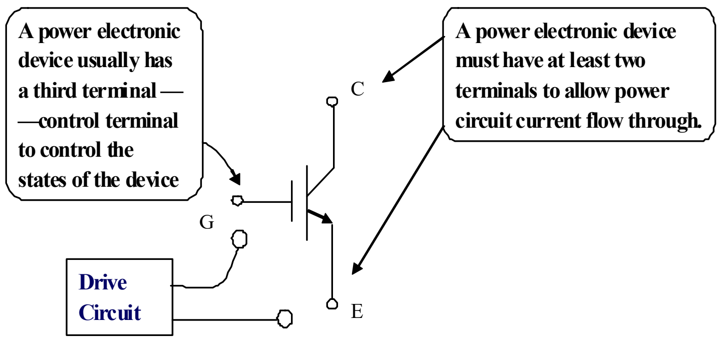
Power BJT

Power Transistor

- Power Transistor is a controlled Device



Power Transistor

- Two types of transistor are extensively used in power switching circuits: bipolar junction transistor (BJT) and Metal Oxide Semiconductor Field Effect Transistor (MOSFET).
- The BJT consists of a ***pnp*** or ***npn*** single-crystal silicon structure.
- It operates by the injection and collection of minority carriers, both electrons and holes, and is therefore termed a '*Bipolar Transistor'.*

Power Transistor

- The MOSFET depends on the voltage control of a depletion width, it is therefore a *Uni-polar Transistor.*
- Unlike the BJT, the MOSFET is a majority carrier device and therefore does not exhibit minority carrier storage delays, so switching times of the MOSFETs are ultra fast.

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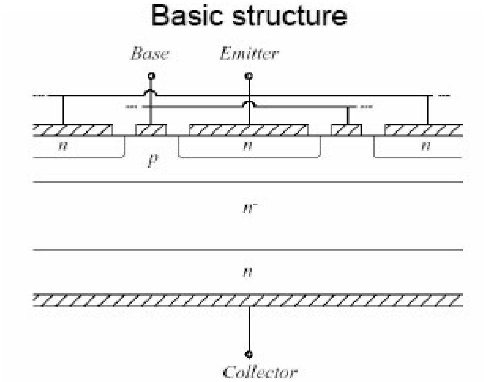
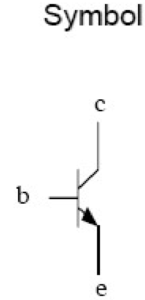
Power BJT Structure

- Power BJT can handle high voltage and large current.





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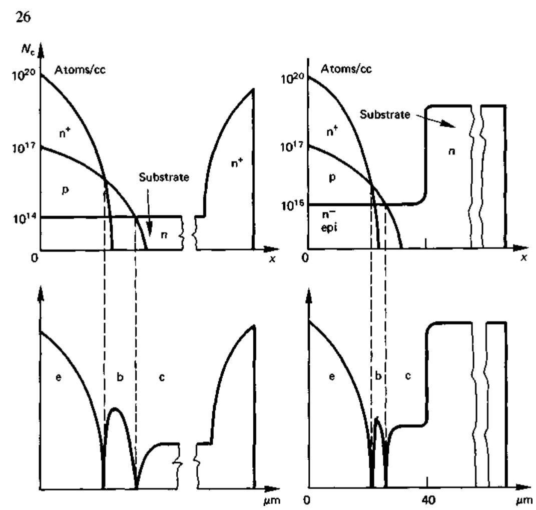
Power BJT doping

A typical high-voltage triple-diffused transistor doping profile is shown below



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Power BJT

- The n-collector region is the initial high-resistivity silicon material and the collector n^+ diffusion is performed first, usually into both sides.
- One n^+ diffusion is lapped off and the p-base and n^+ emitter diffusions are sequentially performed.

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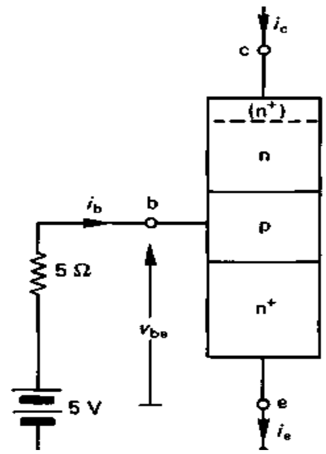
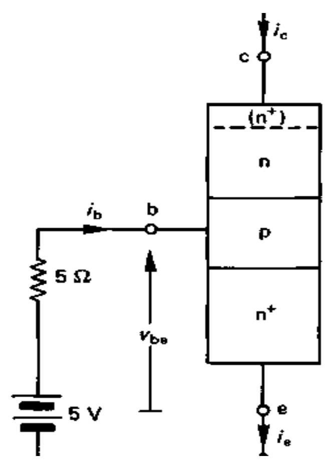
Power BJT Operation

- A simple and qualitative view of the bipolar power switching transistor.
- *npn* bipolar transistor connected in the common *emitter* configuration.



Power BJT Operation

- In this configuration, injection of electrons from the lower n^+p junction into the centre p-region supplies minority carrier electrons to participate in the reverse current through the upper np junction.



Power BJT Operation

- The n^+ region which serves as the source of injected electrons is called the *emitter* and forms the emitter junction with the *p^- base,* while the n-region into which electrons are swept by the reverse bias np junction is called the *collector* and, with the p-base, forms the collector junction

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Power BJT Operation

- To have a 'good' npn transistor almost all the electrons injected by the emitter into the base should be collected.
- Thus the p-base region should be narrow and the electron minority carrier lifetime should be long to ensure that the average electron injected at the emitter will diffuse to the collector ***scl*** without recombining in the base.
- The average lifetime of electrons in the p-base increases as the p-base concentration decreases, that is as the hole concentration decreases.

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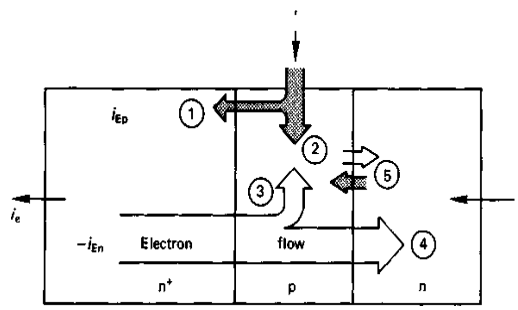
Power BJT Operation

- The fraction of electrons which make it across to the collector is called the *base transport factor,* b_t.
- If we neglect the saturation current at the collector, component 5 in figure below, and such effects as space charge layer recombination, then $i_c = b_t i_{En}$ where i_{En} is the electron component of the total emitter current i_e.



Power BJT Operation

- Electrons lost to recombination in the p-base must be re-supplied through the base contact.
- It is also required that the emitter junction carrier flow should be composed almost entirely of electrons injected into the base, rather than holes crossing from the base region to the emitter.
- Any such holes must be provided by the base current, which is minimised by doping the base region lightly compared with the emitter such that an n^+p emitter results.

Power BJT Operation

- Such a junction is said to have a high *injection efficiency.*
- Holes swept into the base at the reverse-biased collector junction because of thermal generation in the collector must also be accounted for by the base current.
- This base current component is generally very small in high-voltage transistors when in the on-state since the collector scl electric field is small.

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Power BJT Operation

- In the common emitter configuration, the ratio between the base current I_b and the collector current I_c is of practical importance.
- Since the base current is the difference between the emitter and the collector current.
- The factor β, relating the collector current to the base current, is defined as the base-to-collector *current amplification factor.*
- If α is near unity, β is very large, implying the base current is very small compared with the collector current.

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Power BJT Operation

- In power switching applications a transistor is controlled in two states: the *off-state and the on-state.*
- Ideally the transistor should appear as a short circuit when on and an open circuit when in the off-state.
- Furthermore the transition time between these two states is ideally zero. In reality, transistors only approximate these requirements.

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Power BJT Operation

- The two operational states for the power switching transistor are defined as follows.
- ***Cut-off region:*** In this region the emitter junction is not injecting; hence only leakage current flows.
- ***The saturation:*** In traversing from the off-state to the saturated state the transistor passes through the linear operating region, where the collector junction voltage changes from a large reverse bias to a forward bias state.

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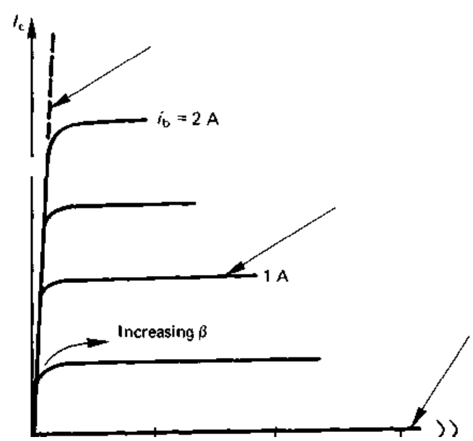
Power BJT Operation

- Both junctions are forward-biased, termed *saturated,* and the collector-to-emitter voltage is almost zero, high current is able to flow.
- This saturated situation represents the switched-on hard mode, and over-saturation exists.
- The gain ***β*** is a minimum in the saturated mode since the neutral base width between the two forward-biased ***scl's*** is at a maximum.

Power BJT Characteristics

The typical BJT collector output characteristics are shown below which illustrates the various BJT operating regions.



Power BJT
Current Gain

- A number of electrical phenomena are of particular importance to the high-voltage, power switching ***BJT***.
- The characteristics to be considered are as a result of the device structure and geometry.
- The gain of a power transistor falls off at both very low and very high current levels.
- At low currents the gain decreases as a result of generation recombination.

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Conductivity Modulation

- At high currents, as the concentration of excess electrons in the base becomes large, the matching excess hole concentration can become greater than the base doped level.
- A balance of holes and electrons must occur in order to maintain a neutral base region.
- Thus holes in the base are injected into the emitter, countering the conversely injected electrons, and thus effectively decreasing the emitter injection efficiency.
- This effect is called *conductivity modulation.*

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First Breakdown

- The collector junction supports the off-state voltage and in so doing develops a wide ***scl***.
- This ***scl*** increases in width with increased reverse bias, penetrating into the base.
- It is unusual that a correctly designed high-voltage power switching ***BJT*** would break down as a result of punch-through of the collector ***scl*** through the base to the emitter ***scl***.

First Breakdown

- Because of the profile of the diffused base, collector junction voltage breakdown is usually due to the avalanche multiplication mechanism, created by the high electric field at the collector junction.
- In the common emitter configuration, the transistor usually breaks down gradually, but before the collector junction avalanches.
- This occurs because the avalanche-generated holes in the collector ***scl*** are swept by the high-field into the base.

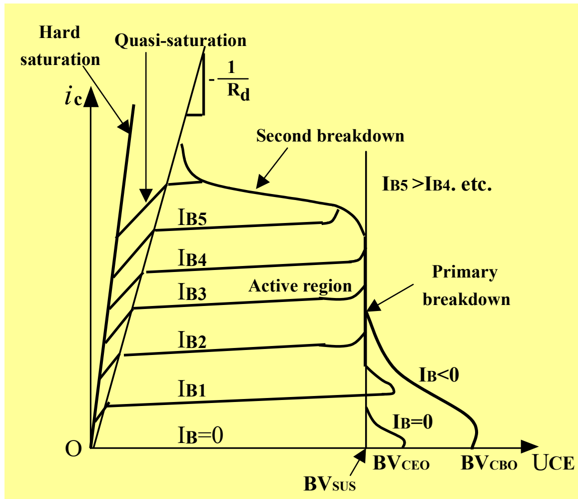
First Breakdown

- The emitter injects electrons in order to maintain base neutrality.
- This emitter junction in turn causes more collector current, creating more avalanche pairs and causing a regenerative action.
- Thus the gain mechanisms of the transistor cause collector emitter breakdown- *first breakdown*

Second Breakdown

- First breakdown need not be catastrophic provided junction temperature limits are not exceeded.
- If local hot spots occur because of non-uniform current density distribution as a result of crystal faults, doping fluctuation etc., *second breakdown* occurs.
- Silicon crystal melting and irrepairable damage results, the collector voltage falls and the current increases rapidly as shown in figure below

Second Breakdown



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Power MOS

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