5.4.6. Breakdown mechanisms in BJTs

The breakdown mechanisms of BJTs are similar to that of p-n junctions. Since the base-collector junction is reversed biased, it is this junction where breakdown typically occurs. Just like for a p-n junction the breakdown mechanism can be due to either avalanche multiplication as well as tunneling. However, the collector doping in power devices tends to be low-doped either to ensure a large enough breakdown voltage – also called blocking voltage – or to provide a high Early voltage. The collector doping in microwave BJTs is typically higher than that of power devices, yet based on the trade-off between having a short transit time through the base-collector depletion region and having a low base-collector capacitance. As a result, one finds that the collector doping density rarely exceeds 10^{18} cm^{-3} and tunneling does not occur.

Instead, breakdown is dominated by avalanche multiplication. The large electric field in the base-collector depletion region causes carrier multiplication due to impact ionization. Just like in a p-n diode, this breakdown is not destructive. However, the high voltage and rapidly increasing current does cause large heat dissipation in the device, which can cause permanent damage to the semiconductor or the contacts.

The breakdown voltage of a BJT also depends on the chosen circuit configuration: In a common base mode (i.e. operation where the base is grounded and forms the common electrode between the emitter-base input and collector-base output of the device) the breakdown resembles that of a p-n diode. In a common emitter mode (i.e. operation where the emitter is grounded and forms the common electrode between the base-emitter input and the collector-emitter output of the device) the transistor action further influences the *I-V* characteristics and breakdown voltage. Base width modulation was described in section 5.4.1 to result in an increase in the collector current with increased collector-emitter voltage. In the extreme case of punchthrough where the base is completely depleted, an even larger increase is observed be it nowhere as abrupt as in the case of avalanche breakdown. Avalanche breakdown of the base-collector junction is further influenced by transistor action in common-emitter mode of operation, since the holes generated by impact ionization are pulled back into the base region which results in an additional base current. This additional base current causes an even larger additional flow of electrons through the base and into the collector due to the current gain of the BJT. This larger flow of electrons in the base-collector junction causes an even larger generation of electron-hole pairs.

To further analyze this effect quantitatively we first write the total collector current, I_C, in response to an applied base current, I_B:

$$I_C = \boldsymbol{b}(I_B + (M-1)I_C) \tag{5.4.15}$$

Where the term $(M - 1)\ I_C$ was added to the base current to include the holes generated due to impact ionization. This equation can be rearranged to yield:

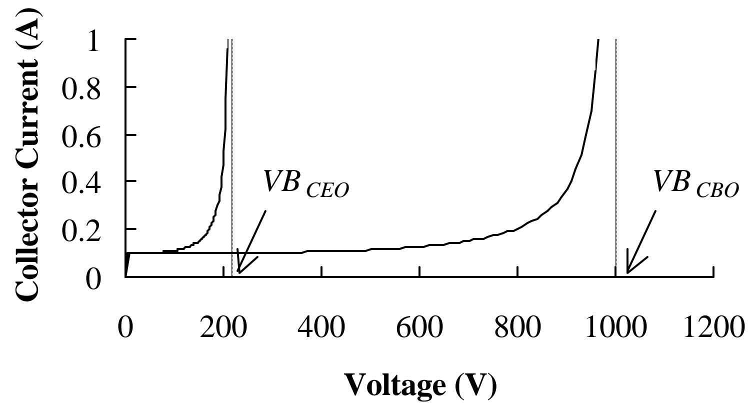
$$I_C = \frac{\boldsymbol{b}\, I_B}{1 + \boldsymbol{b} - \boldsymbol{b}\, M} \tag{5.4.16}$$

The collector current will therefore approach infinity as the denominator approaches 1. From this equation and combining with equation 4.5.6 one finds that the common emitter breakdown

voltage equals:

$$V_{br,CEO} = \frac{V_{br,CBO}}{(\boldsymbol{b}+1)^{1/m}} \tag{5.4.17}$$

The common emitter breakdown voltage as characterized by the open base breakdown voltage, VB_{CEO}, is therefore significantly less than the open emitter breakdown voltage, VB_{CBO}.



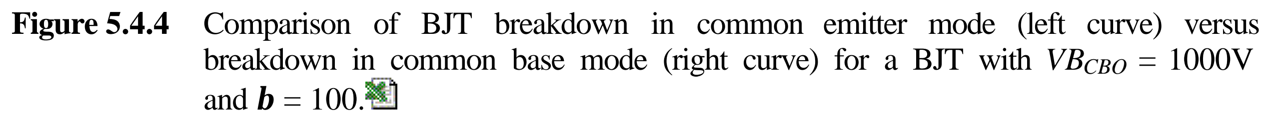


Figure 5.4.4 Comparison of BJT breakdown in common emitter mode (left curve) versus breakdown in common base mode (right curve) for a BJT with VB_{CBO} = 1000V and $\boldsymbol{b}$ = 100.