4.2. Some non ideal characteristics due to transistor scaling and voltage limitations

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Goal;

　　To understand the physical reasons for non ideal characteristics such as,
- High doping effects in the emitter
- base pushout effect
and the voltage limitations caused by,
-BV $_{CEO,}$

Ref :　1. Semicoductor theory with NANOCAD,
　　　　　Daeyoung Sa 2003(Korean)
　　　　2. Grove, Phys. and Tech. of Semicoductor devices.

A. Scaling theory of Bipolar Transistor

As the density of the chip composed of the 'Bipolar Junction Transistor' is increased, the emitter area, A_E, is reduced ($A_E'=A_E/s^2$ where s>1 is the scaling parameter). Generally, the speed of the circuit is proportional to the collector current[1], the collector current tends to be constant even though the emitter area is reduced. Due to this trend, the collector and emitter currents density increases with the factor of s^2.

Also, in order to increase the speed of the transistor, W_t(the base width) tends to decrease. This trend causes the increase in the Early effect and the decrease in the punch through voltage between collector and base(decrease in BV $_{CEO}$). In order to avoid

degradation in BV $_{CEO}$, the doping concentration in the base region increases. The scaling trends decreases the transitor r.

<Summary: Two factors in the scaling. A $_E$ tends to decrease and speed tends to increase, resulting in increase in the current density and decrease in W_b. >

B. High doping effects in the emitter region.

— Two factors become important in determining the emitter efficiency; increase in $n_{i,\,eff}$ in the emitter region and decrease in the life time as the emitter doping level increases. Both effects decrease the emitter efficiency by increasing the hole injection in the emitter(or increase in the base current).

- the increase in $n_{i,\,eff}$ due to the bandgap narrowing has been studied in chapter 1. Net effect of the increase in $n_{i,\,eff}$ in the emitter region is the decrease in the emitter efficiency, so is the r.

- the decrease in the life time in the emitter region is caused by another mechanism than the SRH recombination called the 'Auger recombination'. The phenomenon is the inverse of the 'impact ionization' where one particle results in three particles as the result of the impact ionization.
  The Auger process can be described in the following figure, where electron, electron and hole are recombined. The difference in the momentum is given to another electron so the momentum as well as energy are conserved during the process.
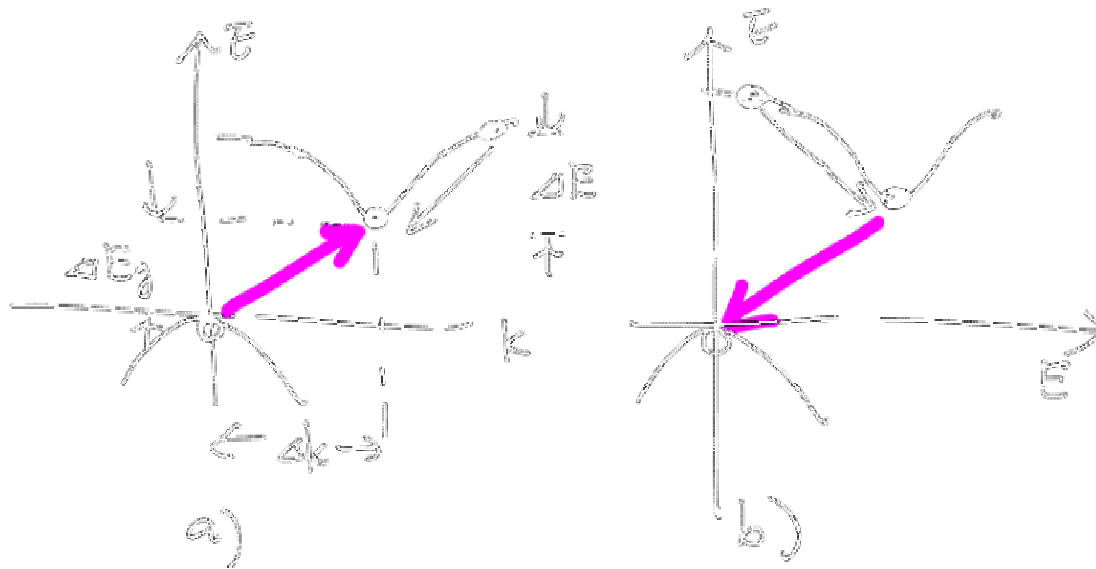
Fig. a) impact ionization and b) the Auger recombination process

C. Base push out effect.

- One of the most important mechanims which is caused by the increase in the collector(also emitter) current density. The increase in the current density causes the increase in the carrier(electrons in the BC junction for the case of NPN transistor). If the electron velocity is v_{sat} , assuming that the electric field in the BC junction large so that carriers drift with the saturation velocity(in the case silicon v_{sat} C 10^7 cm/sec.

  Then electron concentration in the BC junction is

  $$n = ⌐ Jc ⌐ / q \, v_{sat}.$$

  The electron cencentration in the BC junction change the charge density($N_ε$ in the base side and N_d in the collector side) so that the electric field profile changes. As the current density increases to the point when,

  $$n = N_{dc} \text{ (doping concentration of collector)},$$

½ Å E =0, meaning that the energy band in the region changes and the neutral base region **extends** towards the collector region. The phenomenon is called the 'base push out' effects and results in many undesirable characterstics to the transistor such as,
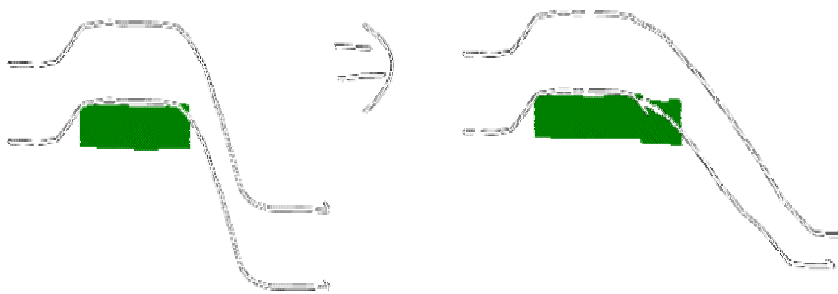
Fig. Base push out effect. Notice that the change in the slope of the band in the BC region.

    - decrease in the collector current (by decreasing the minority carrier slope in the neutral base region), thereby decreasing in transistor γ value,
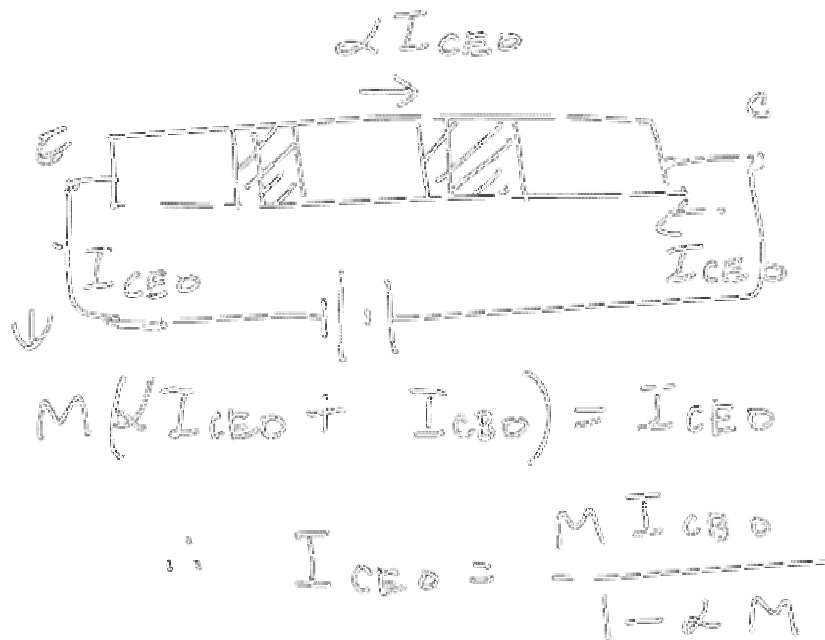   - decrease in the transistor speed due to increase in the base transit time, and so on, so forth.

The following graph shows a typical 'Gummel plot' and ž - Ic characteristics of the bipolar transitor.
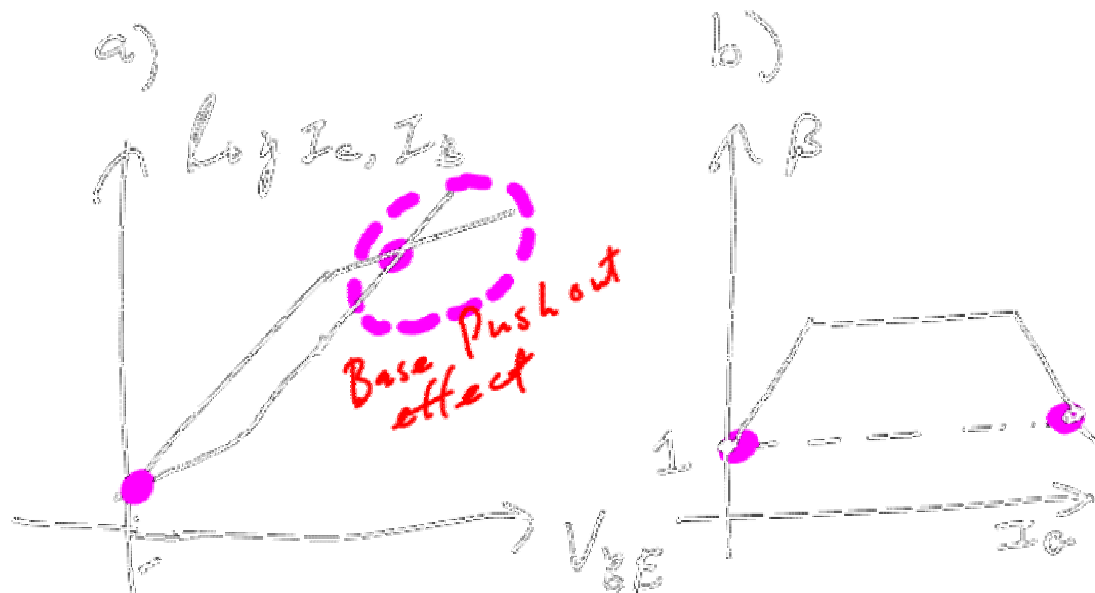
D. Voltage limitation; BV $_{CEO}$

One of the important limitations of the bipolar transistor is caused by 'amplification' of the generation current in the BC junction. The characteristics can be best understood in the BV $_{CEO}$ measurement where 'base' is open while the collector voltage is applied with the emitter as the reference(or ground).

-When the multiplication(M) occurs in the BC junction due to high electric field in the steady state,

$$\alpha I_{CBO}$$
$$\rightarrow$$

$$I_{CBO}$$

$$I_{CBO}$$

$$M(\alpha I_{CBO} + I_{CBO}) = I_{CEO}$$

$$\therefore \quad I_{CEO} = \frac{M I_{CBO}}{1 - \alpha M}$$

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<comment> The situation is similar to what happens in the floating body SOI transistor.

<Avalanche photo transistor>
In the case when generation due to light occurs in the BC junction in addition to the thermal generation,

$\qquad I_{CBO_i}$ = thermal generation in the BC junction area +

$\qquad\qquad G_L$ in the area.

Then G_L is amplified by $M/(1- M \gamma)$.