Heterojuction bipolar transistor (HBT)

The heterojunction bipolar transistor (HBT) differs from the traditional homojunction bipolar transistor (BJT) in that the emitter layer is composed of a different semiconductor from the base, as a result the doping profile can be changed in favor of frequency response. The junction between dissimilar semiconductors is called heterojuction. The semiconductor for the emitter layer is chosen so that the bandgap energy is greater than that of the base semiconductor material.

Semiconductor	Bandgap energy in eV
GaAs	1.424
AlGaAs	1.758

Table 1: Bandgap energies for different semiconductors (1)

HBT device structure

Heavily doped n+ GaAs layers form low-resistance ohmic contacts for the emitter and collector contact. A heavily doped p+ GaAs layer is used for the base in order to reduces the base and base contact resistance. Furthermore the Early effect is reduced as there is just a minimum change in the base width when the base-collector reverse bias is increased. The high base doping makes the device less susceptible to punch through and the base can be made thinner resulting in a faster transistor. The collector is lightly n doped. Because of the higher base doping, a higher collector doping (compared to BJT) is possible without punch through, lowering the collector resistance.

Since, the bandgap energies are different, a discontinuity in the bands appears reducing emitter efficiency. The use of grading layers improves electron movement from the emitter to the base. Additionally space-charge recombination currents at the interface notch are reduced and the turn-on voltage is lowered. The potential barriers for hole injection ΔV_p and electron injection ΔV_n in a graded emitter-base junction differ by the bandgap difference ΔE_g between the AlGaAs emitter and the GaAs base. The electrons injected from the emitter to the base therefore see a lower barrier than the holes injected from the base into the emitter. Because of this a low emitter doping concentration is used which decreases the emitter–base junction capacitance, increasing the transition frequency f_T.

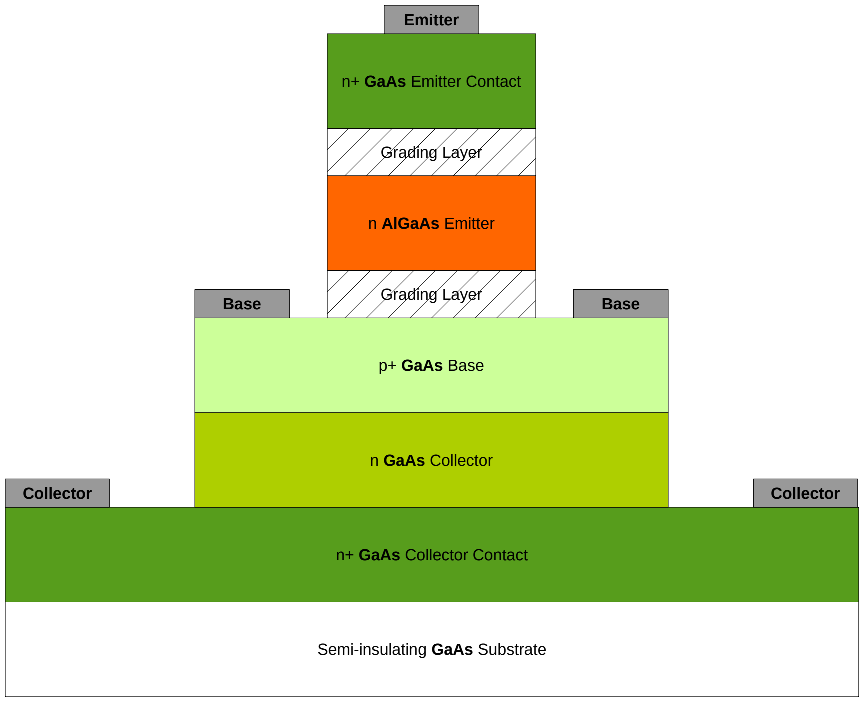

Figure 1: Structure of a NPN AlGaAs/GaAs HBT

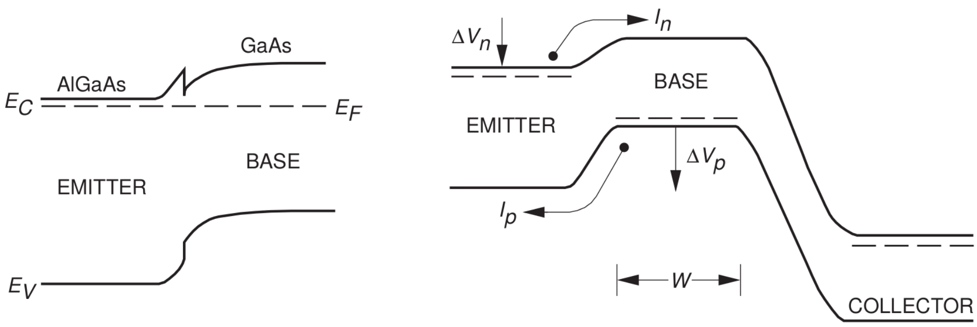

Figure 2: Band diagram of a AlGaAs/GaAs HBT: abrupt emitter–base junction on the left and a graded emitter–base junction on the right (2)

Operation of a HBT

The HBT works exactly as a BJT. The base-emitter juction is forward biased and the collector-base junction is reversed biased. The equilibrium is disturbed and electrons are injected from the emitter into the base. They diffuse across the base until they reach the edge of the base-collector depletion region and are immediately accelerated across the base-collector junction into the collector where they are majority carriers and can contribute to the collector current. The base current is due to the holes diffusing from the base into the emitter and there is also a small contribution from any electrons that fail to make it across the base because they recombine.

The ratio of electron current to hole current in the general case where the emitter and base may be made of different semiconductors is:

$$\frac{I_n}{I_p} = \frac{D_n N_D L_p}{D_p N_A W_B} \cdot \left(\frac{{n_{iE}}^2}{{n_{iB}}^2} \right) \tag{1}$$

N_A and N_D are emitter and base doping, ${n_{iB}}^2$ and ${n_{iE}}^2$ are the electron-hole products for the emitter and base, D_p and D_n are the hole and electron diffusion constants, W_B is the base width and L_p the hole diffusion length.

For the HBT ${n_{iB}}^2$ and ${n_{iE}}^2$ are no longer the same.

$${n_i}^2 = N_c N_v e^{-\frac{E_g}{k_b T}} \tag{2}$$

$$\frac{I_n}{I_p} \sim \frac{D_n N_D L_p}{D_p N_A W_B} e^{\frac{\Delta E_g}{k_b T}} \tag{3}$$

For sufficiently large ΔE_g ($\Delta E_g = 0$ for a BJT), I_p will be completely suppressed, virtually independent of either the emitter and base doping or base width. For example, at an Al mole fraction of 30%, $e^{\frac{\Delta E_g}{k_b T}} \sim 10^6$. With this additional factor of 10^6 (compared to BJT), the device designer may choose doping levels and base width freely in order to optimize other aspects of performance, such as speed. Equation 3 is just an approximation, since the effect of traps in the emitter-base junction is neglected.

Appliciations of HBTs

HBTs are used for digital and analog microwave applications with frequencies up to several hundred GHz. E.g. in power amplifiers in mobile telephones and laser drivers. In microwave application, a lower emitter capacitance reduces the noise figure significantly.

References

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