

Physics and Technology of Semiconductor Devices

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Preface

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The 1950's was a period of prominence and most of the research. The 1960's can be characterized by devices and integrated germanium devices.

The purpose of this book is to present the state of the art and technology of semiconductor technology. To be successful in the design and the operation of semiconductor devices, the designer must be familiar with the fabrication and the operation of these devices by other technologies. It is often difficult to be very difficult to concentrate on the alloy germanium and silicon diode. As a result, the characteristics of the devices are often concentrated on the alloy devices. In dealing with the design of these devices.

After a brief introduction into three parts.

below unity at a frequency of the same order of magnitude as given by the above criterion.

It is interesting to compare the transit time with the base transport factor α_T given earlier. It is evident from Equations 7.21 and 7.28 that the base transport factor is related to the ratio of the transit time across the base to the lifetime by

$$\alpha_T = 1 - \frac{t_{tr}}{\tau_p} \quad (7.29)$$

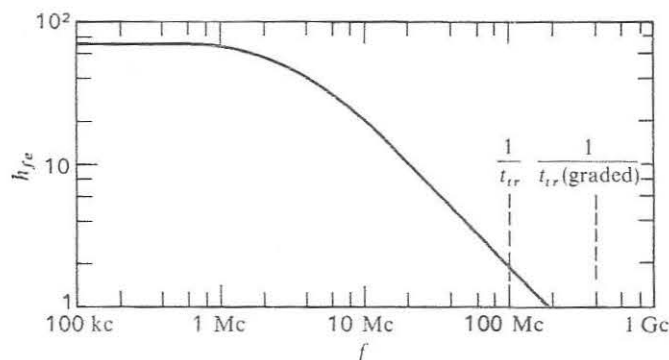


Fig. 7.12 The effect of signal frequency on the common-emitter current gain of the *pnp* transistor. ($I_C = 50$ ma, $V_{CE} = -3$ v)

Physically, this is very suggestive—the probability of recombination of an injected hole in the base region will indeed depend on this ratio.

b. Graded Base Regions

So far we have based our discussion on the idealized transistor model in which the distribution of the impurities in the base region was assumed to be uniform. In double-diffused transistors, the distribution of impurities in the base region is not uniform, but is quite strongly graded. The estimated distribution of impurities in our *pnp* transistor is shown in Figure 7.13. Note the very significant variation of impurity concentration across the base region. This impurity concentration profile will bring about a similar variation of majority carrier concentration in the base region. However, in equilibrium no current flows so that an electric field must exist in the neutral base region. This electric field will counterbalance the diffusion current due to the concentration gradient of majority carriers existing there. (This is also evident from the corresponding band diagram shown in Figure 7.14.) If minority carriers are now injected into the base, their motion will be affected by the finite electric field which is present in the neutral base region.

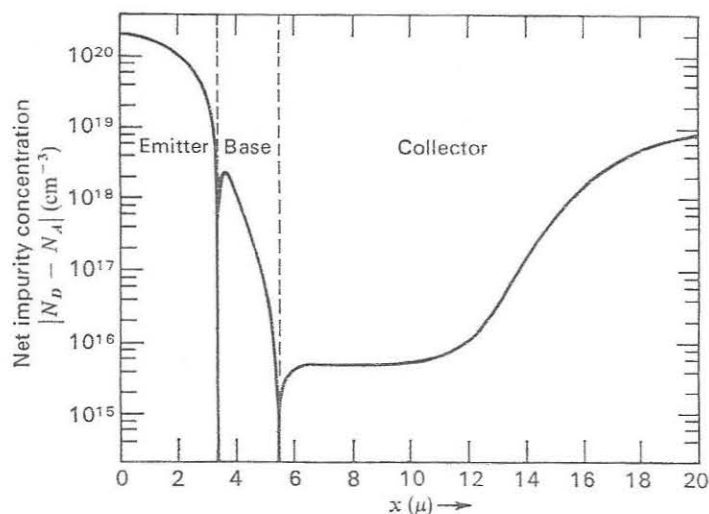


Fig. 7.13 The impurity distribution in the *pnp* transistor. (Estimated on the basis of diffusion conditions.)

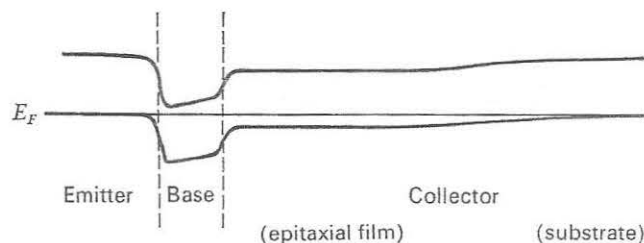


Fig. 7.14 The corresponding band diagram, in equilibrium.

In the case of *pnp* transistors, because of the impurity concentration gradient, the electrons within the base tend to diffuse toward the collector. Thus an electric field must be present, pushing the electrons toward the emitter-base junction. This same electric field will then be of such direction as to aid the motion of injected holes. Thus *the injected minority carriers will now move not only by diffusion but also by drift* due to the existence of this electric field. As a result, the transit time across the base will decrease and the upper frequency limitation of the transistor associated with this transit time will increase.² Correspondingly, the transport factor will also increase.

To provide an indication of the effect of this built-in electric field, in Figure 7.15 theoretical calculations³ of the transit time are shown as a function of the ratio of the concentration of the base impurity at the

emitter-base junction to that at the collector-base junction. In these calculations, the impurity distribution in the base region was approximated by an erfc-type distribution. The transit time for the *pnp* transistor, corrected by using Figure 7.15, is also indicated in Figure 7.12.

The calculations of Moll and Ross,³ on which Figure 7.15 was based, also show that in the derivation of the currents flowing in a transistor, the quantity $(N_{DB}W_B)$ in the denominator of Equation 7.12 and in subsequent

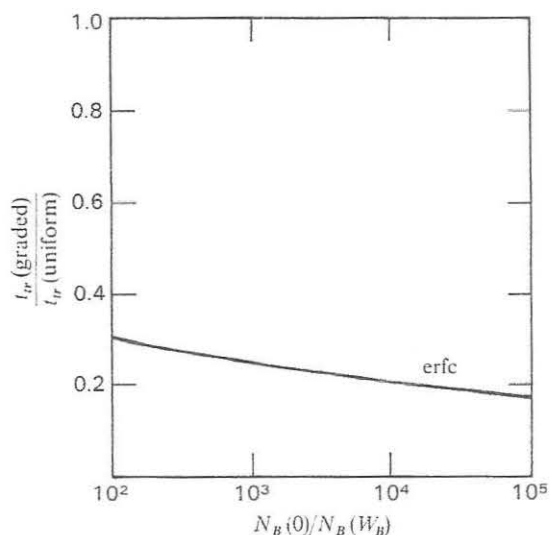


Fig. 7.15 Reduction in base transit time due to the graded impurity concentration across the base region. $N_B(0)$ and $N_B(W_B)$ are the base-impurity concentrations at the emitter-base and collector-base junctions, respectively.³

equations is replaced by the total number of impurities in the base per unit area Q_B , given by

$$Q_B \equiv \int_0^{W_B} N_{DB}(x) dx. \quad (7.30)$$

Furthermore, N_{DB} itself is replaced by its value at the emitter-base junction, $N_{DB}(0)$. Otherwise, the equations remain unchanged. With these changes, results based on the idealized transistor model can be readily adapted to the consideration of double-diffused transistors.

c. Early Effect

The effect of the collector-base reverse bias on the common emitter current gain h_{FE} is not explicit in the equations of the previous sections.