

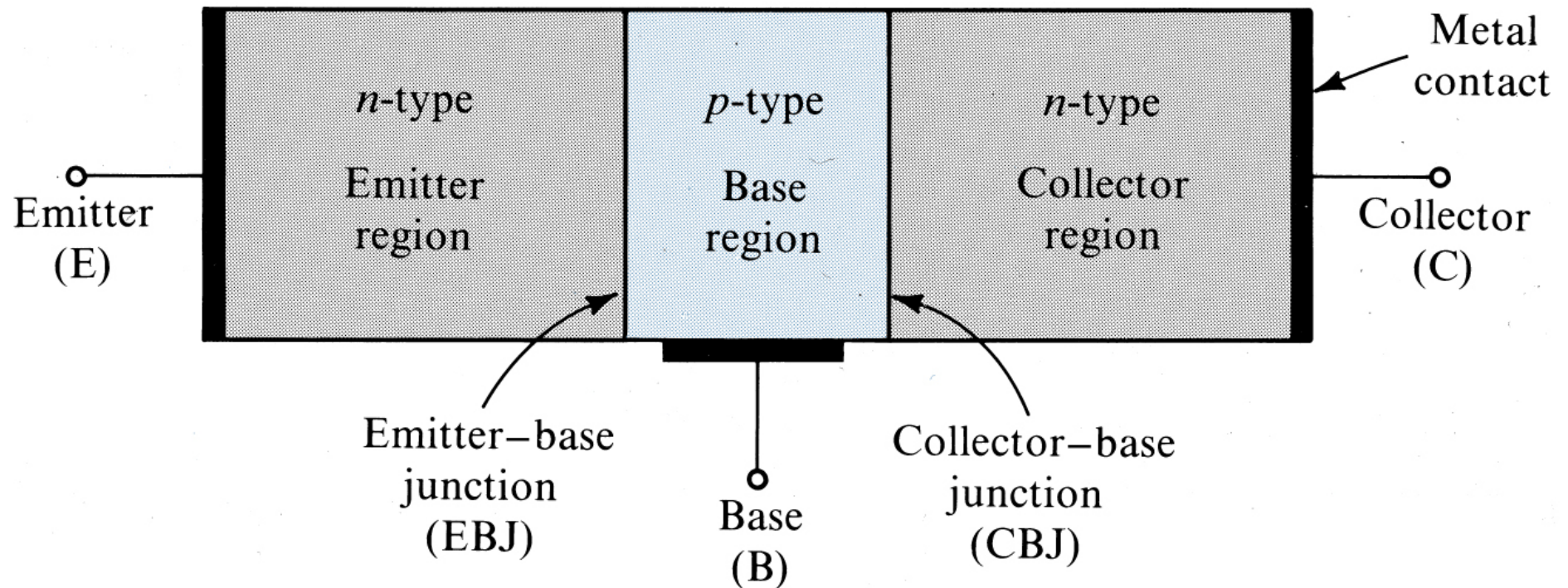
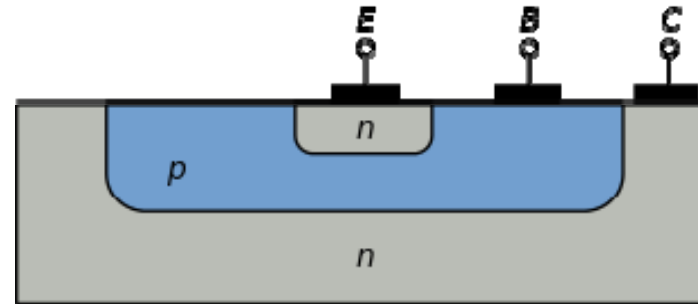
**Tema 6: Transistores bipolares de unión:
introducción, estructura, tipos, descripción,
funcionamiento. Secuencia de fabricación.**

Lecturas recomendadas:

“Circuitos electrónicos” Cap.2. Shilling-Belove. Ed. McGraw-Hill

“Microelectrónica” Cap.3. Millman-Grabel. Ed. Hispano Europea

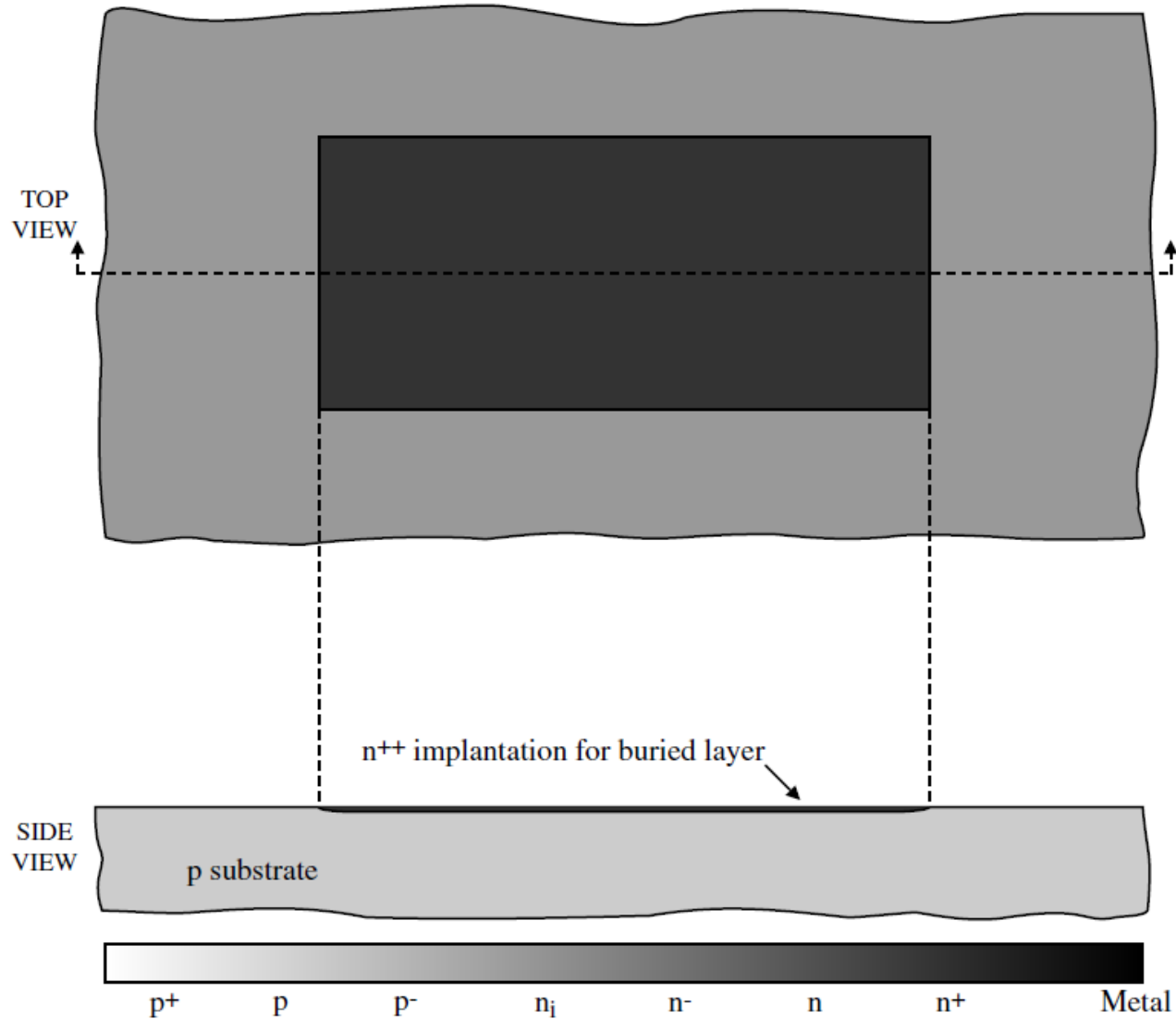
TRANSISTOR BIPOLAR DE UNIÓN (BJT) NPN



IMPLANTACIÓN DE LA CAPA ENTERRADA

Implantation of the Buried Layer (Mask Step 1)

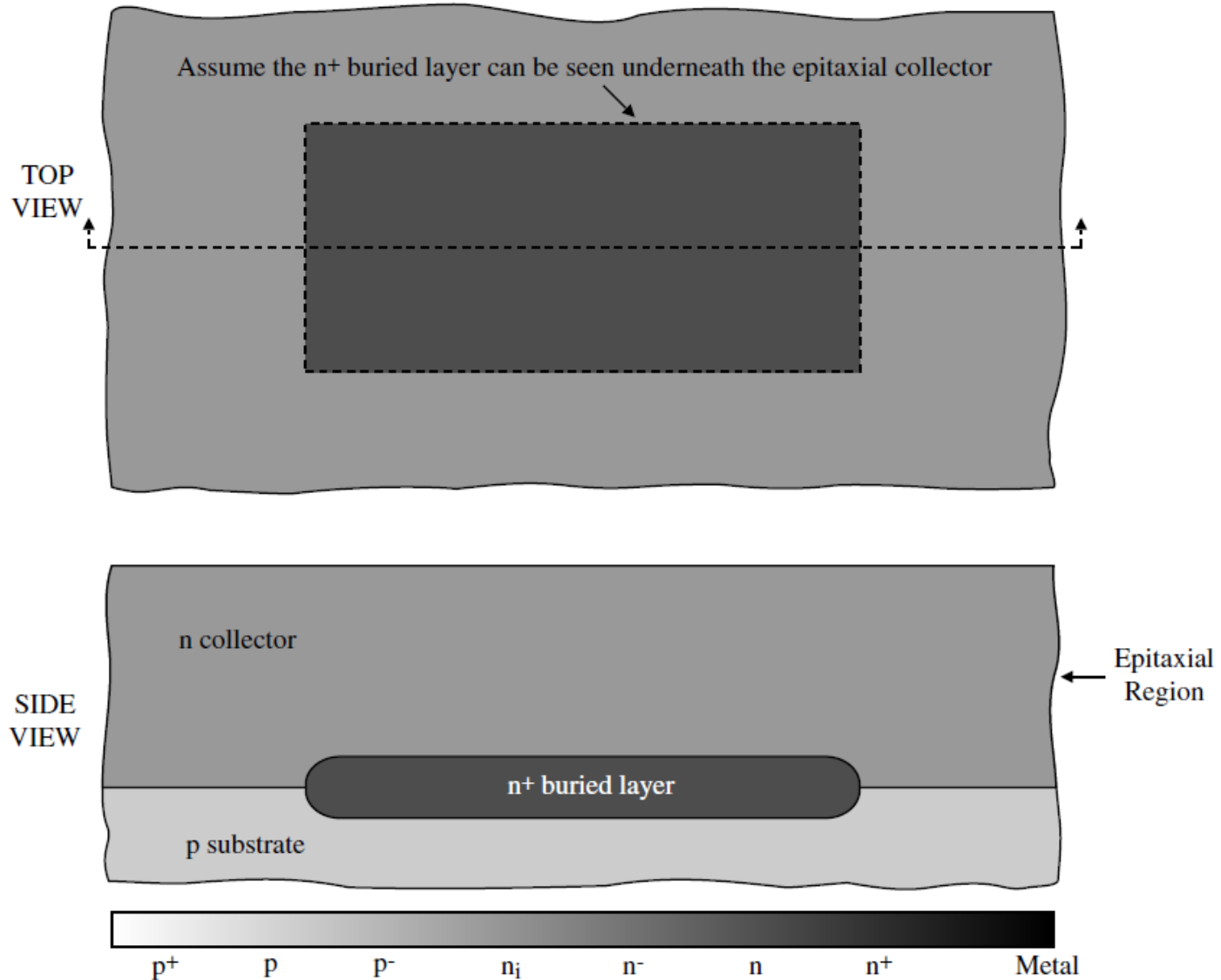
Objective of the buried layer is to reduce the collector resistance.



CRECIMIENTO DE LA CAPA EPITAXIAL

Epitaxial Layer (No Mask Required)

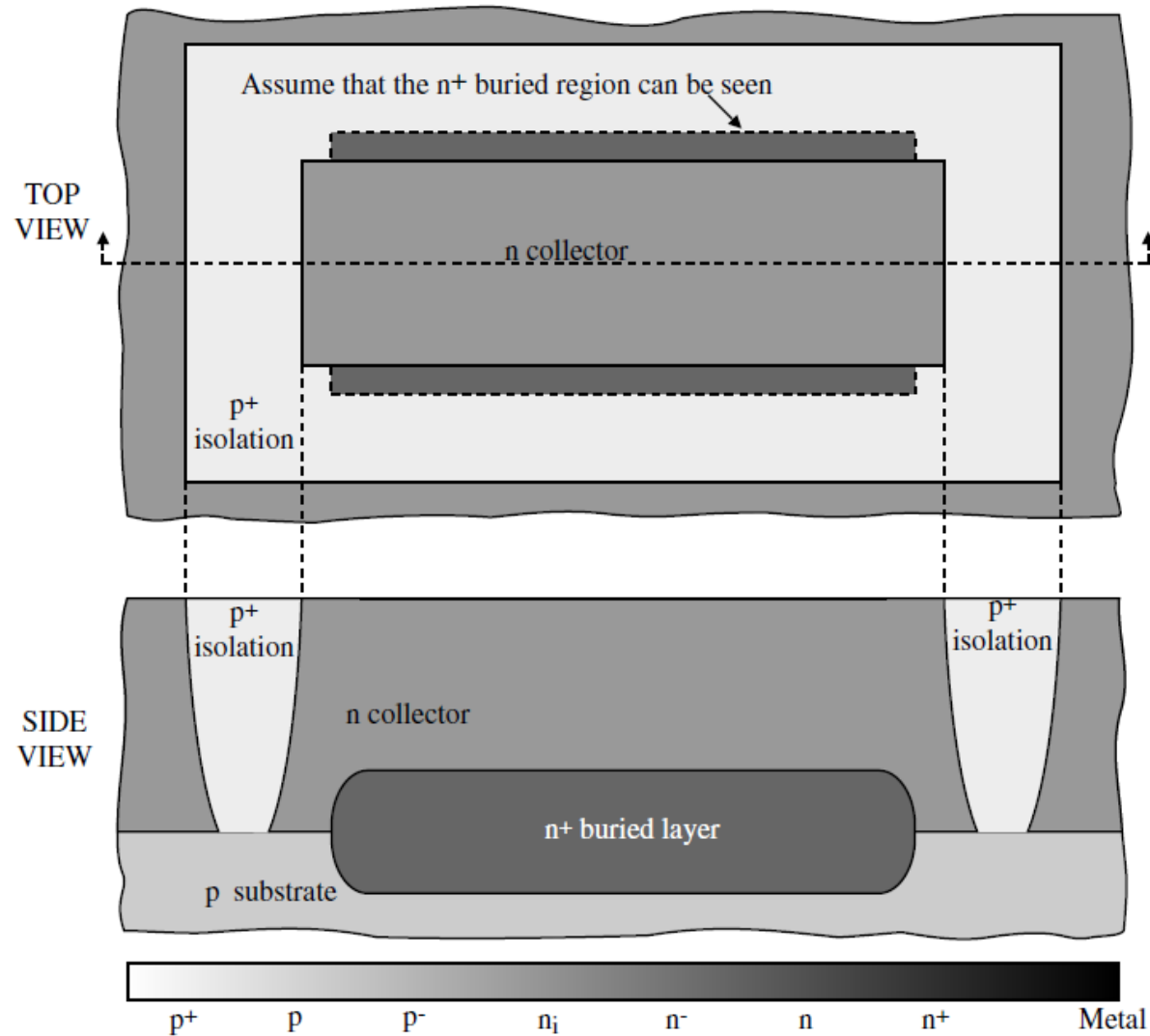
The objective is to provide the proper n -type doping in which to build the npn BJT.



DIFUSIÓN DE AISLAMIENTO

p^+ isolation diffusion (Mask Step 2)

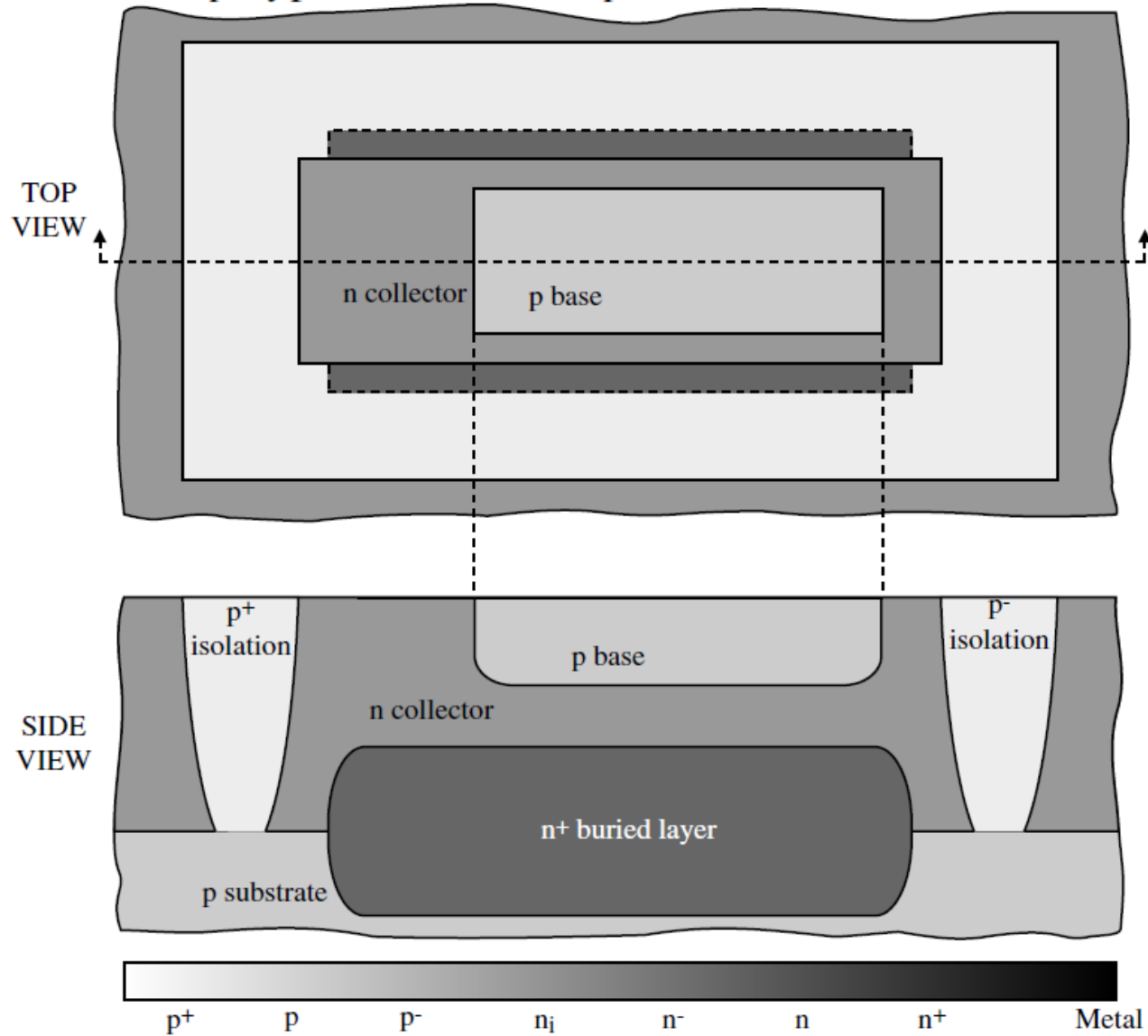
The objective of this step is to surround (isolate) the n pn BJT by a p^+ diffusion. These regions also permit contact to the substrate from the surface.



DIFUSIÓN P DE LA BASE

Base p -type diffusion (Mask Step 3)

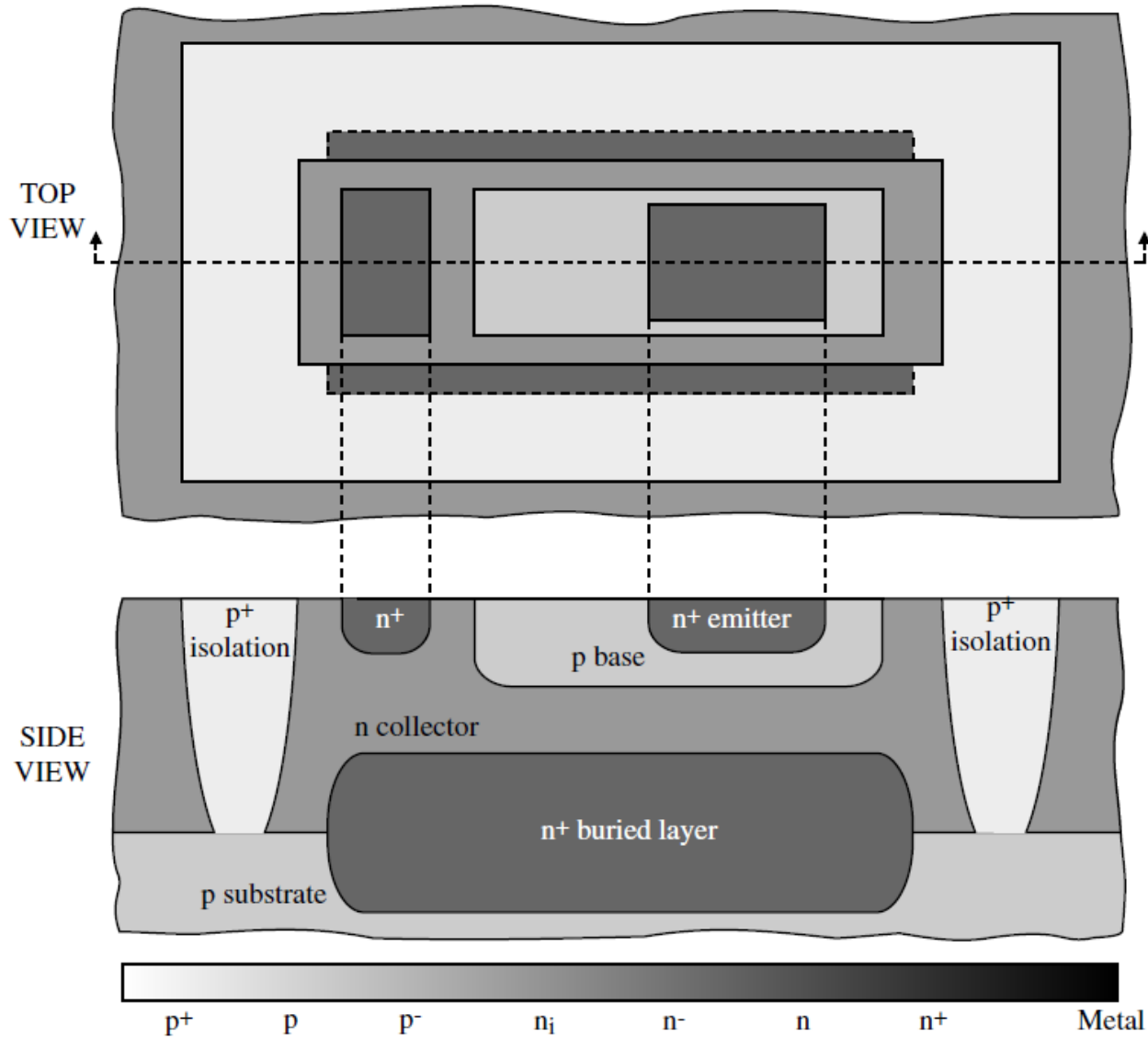
The step provides the p -type base for the npn BJT.



DIFUSIÓN N⁺ DE EMISOR

Emitter n⁺ diffusion (Mask Step 4)

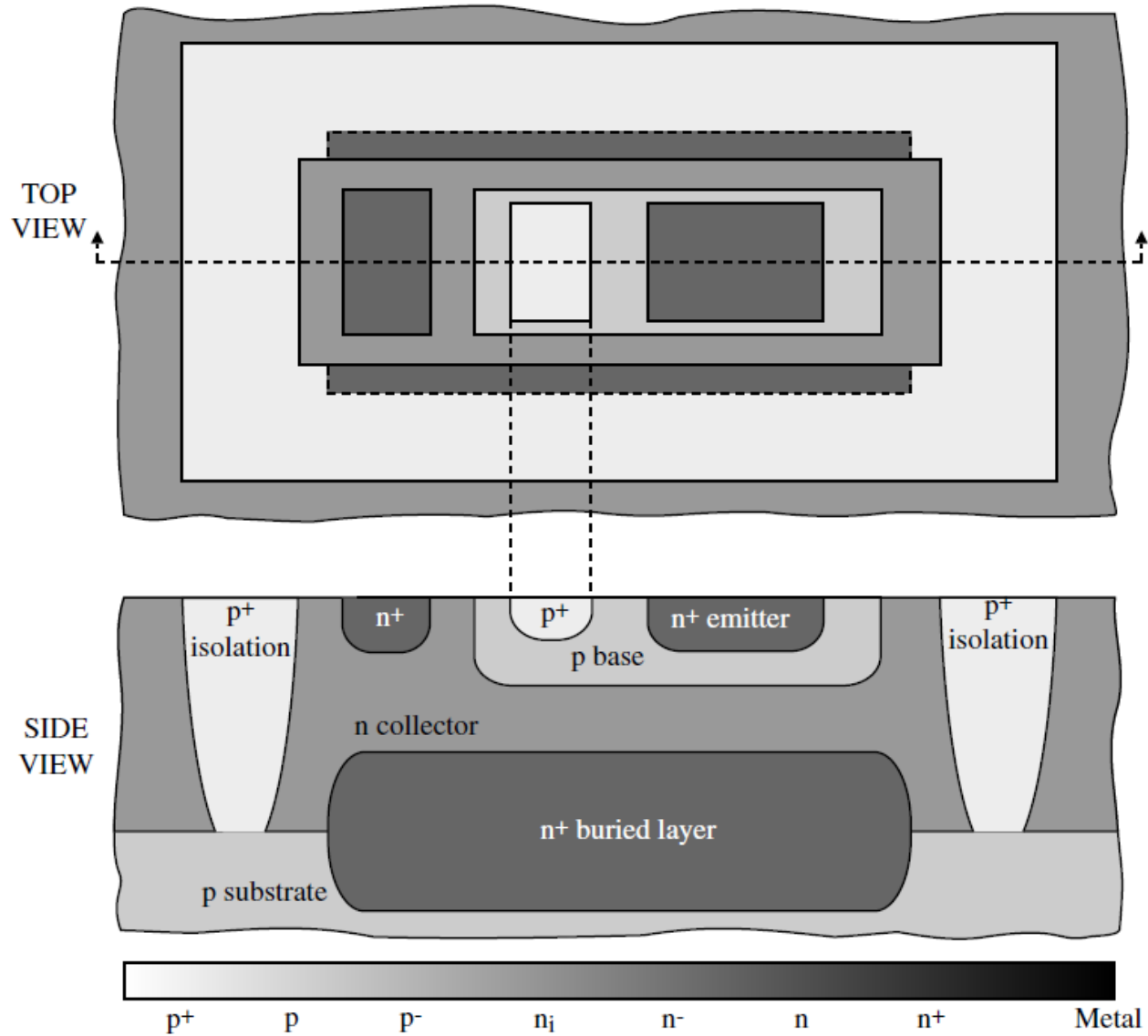
This step implements the n⁺ emitter of the npn BJT and the collector ohmic contact.



DIFUSIÓN P⁺ DE CONTACTO ÓHMICO

p⁺ ohmic contact (Mask Step 5)

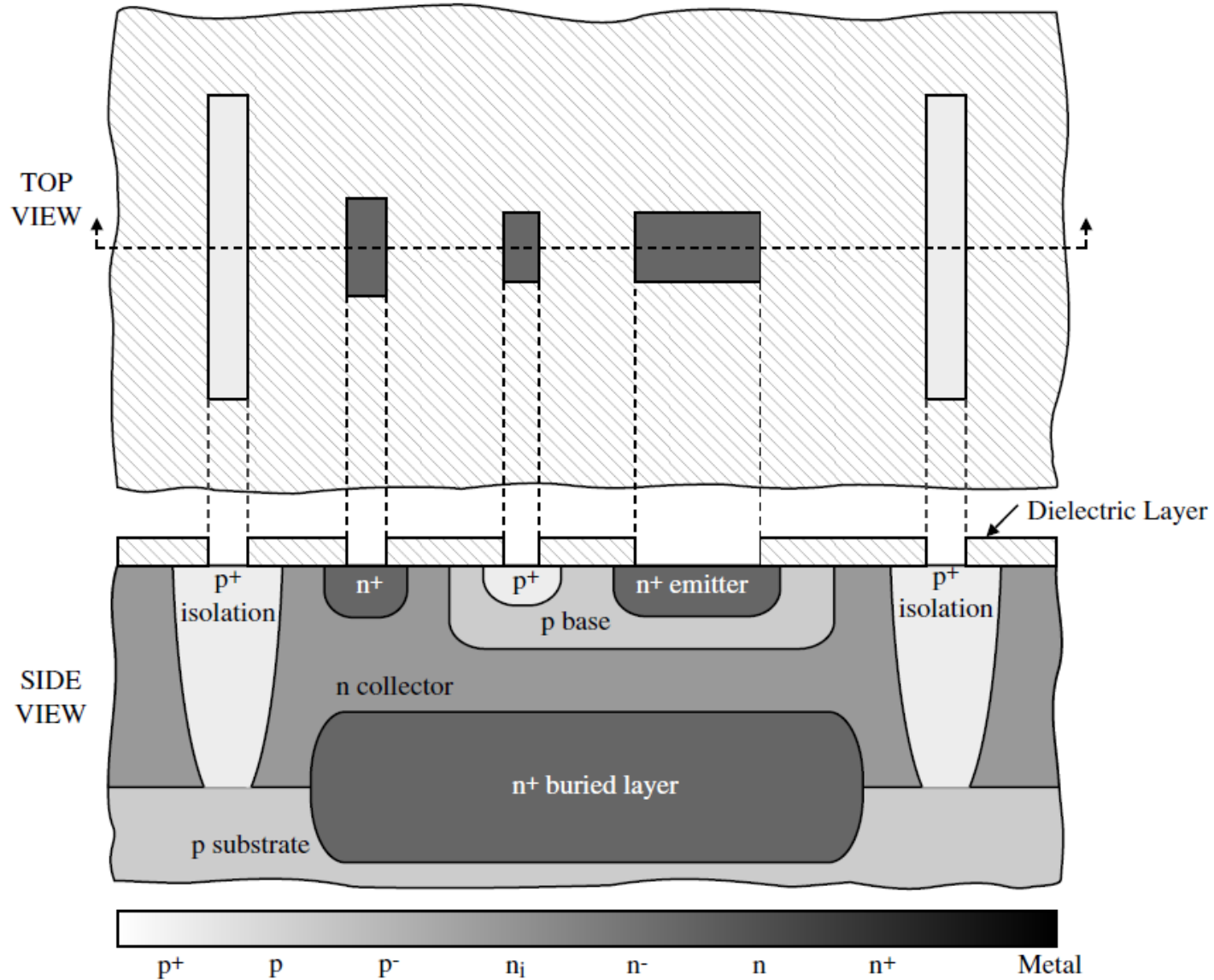
This step permits ohmic contact to the base region if it is not doped sufficiently high.



DEFINICIÓN ÁREAS DE CONTACTOS

Contact etching (Mask Step 6)

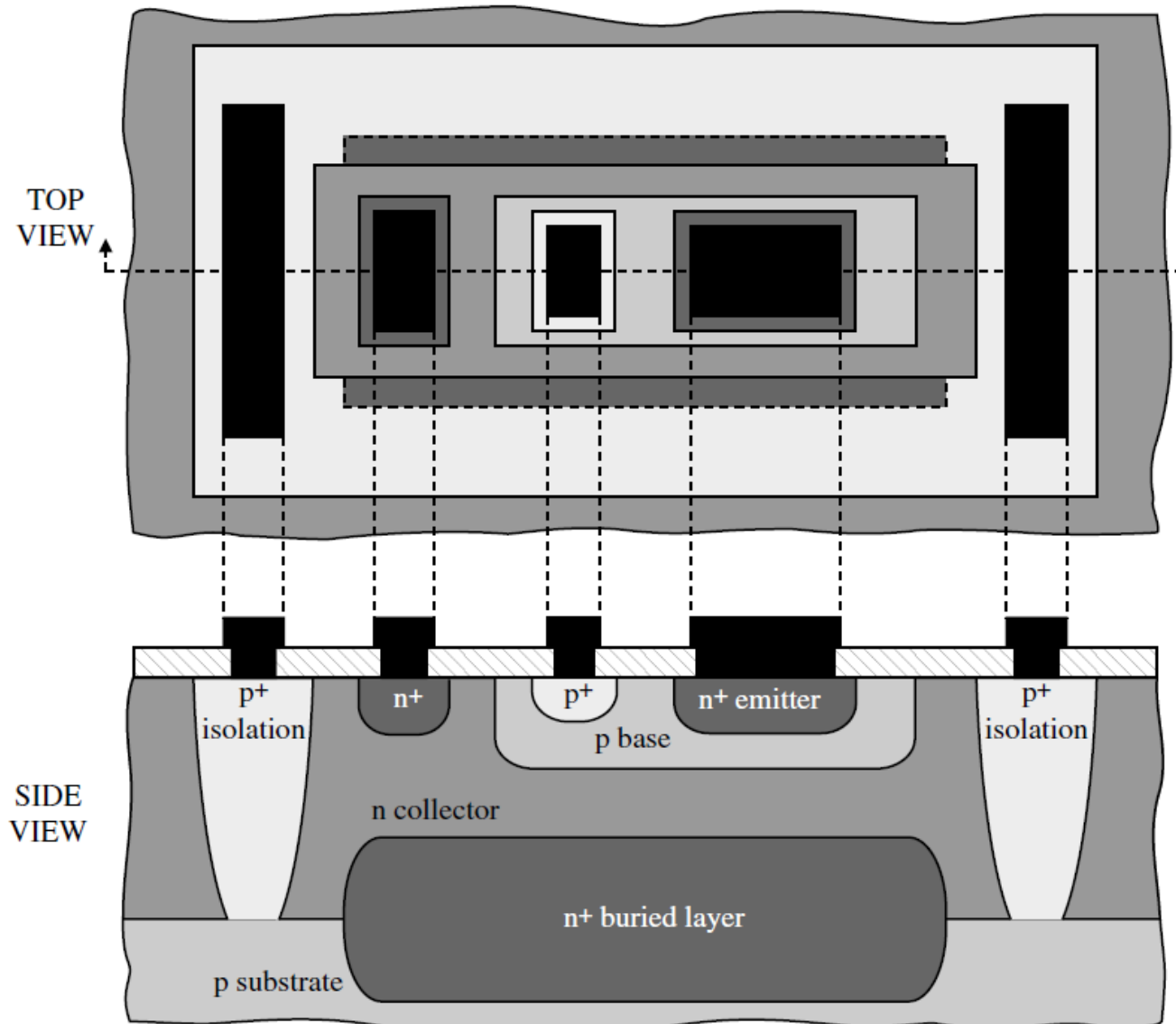
This step opens up the areas in the dielectric area which metal will contact.



DEFINICIÓN DE CONTACTOS METÁLICOS

Metal deposition and etching (Mask Step 7)

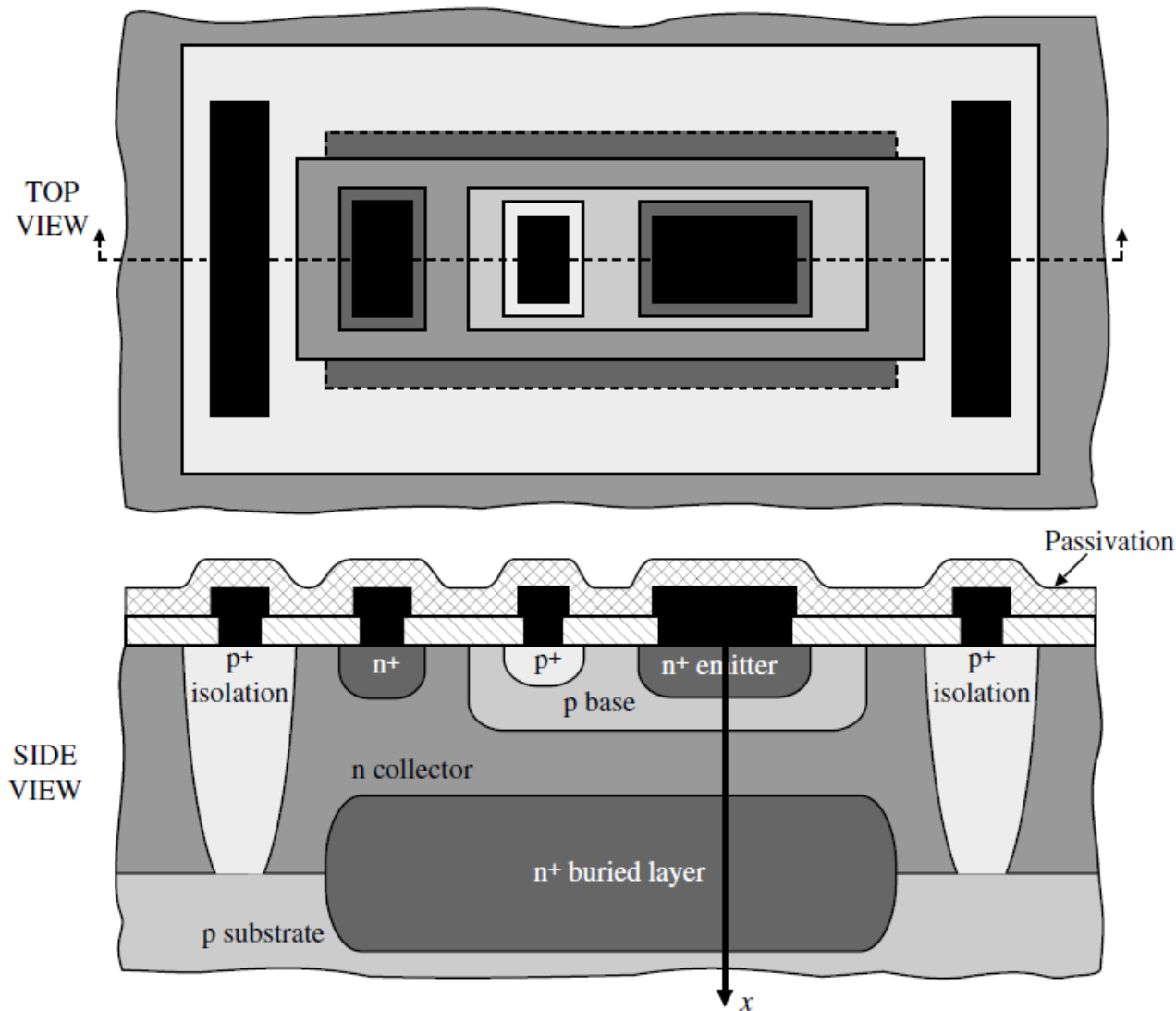
In this step, the metal is deposited over the entire wafer and removed where it is not wanted.



PASIVACIÓN

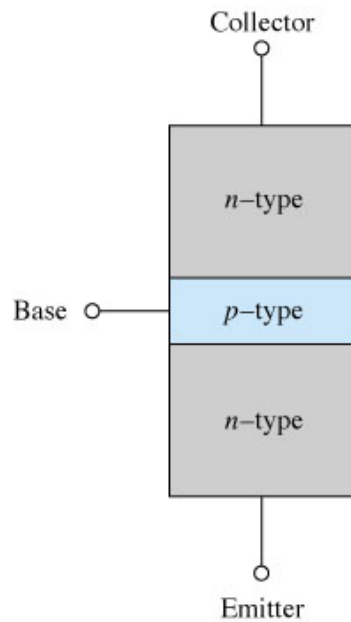
Passivation (Mask Step 8)

Covering the entire wafer with glass and opening the area over bond pads (which requires another mask).

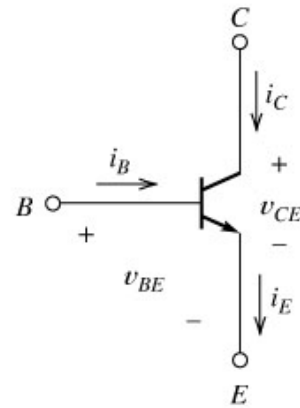


TIPOS DE TRANSISTORES BJT

NPN

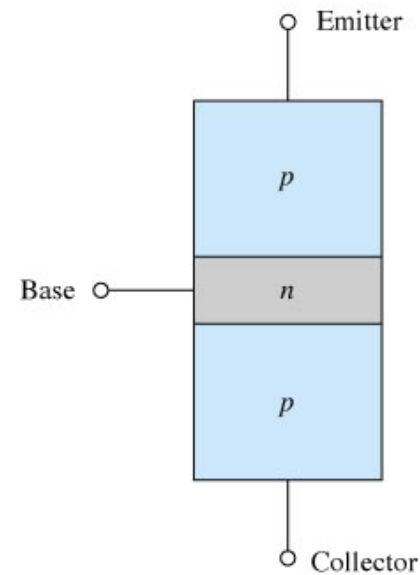


(a) Simplified physical structure

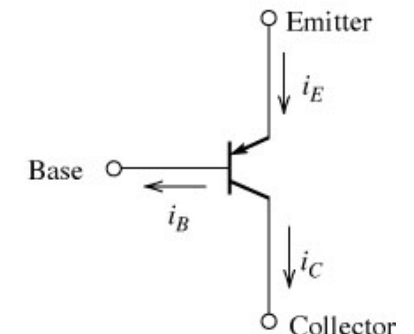


(b) Circuit symbol

PNP

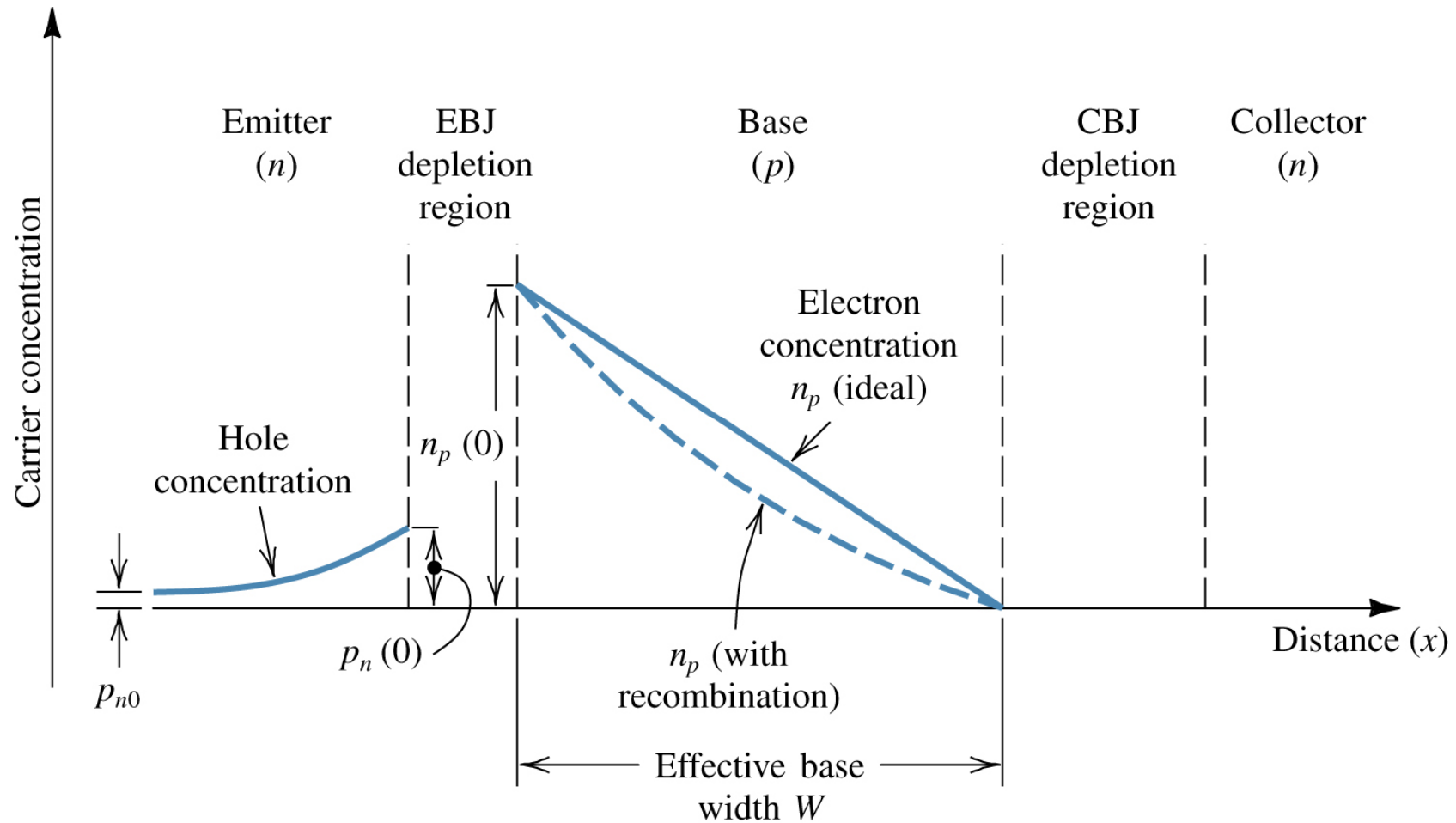


(a) Physical structure



(b) Circuit symbol with reference directions for currents

CRITERIOS DE DISEÑO

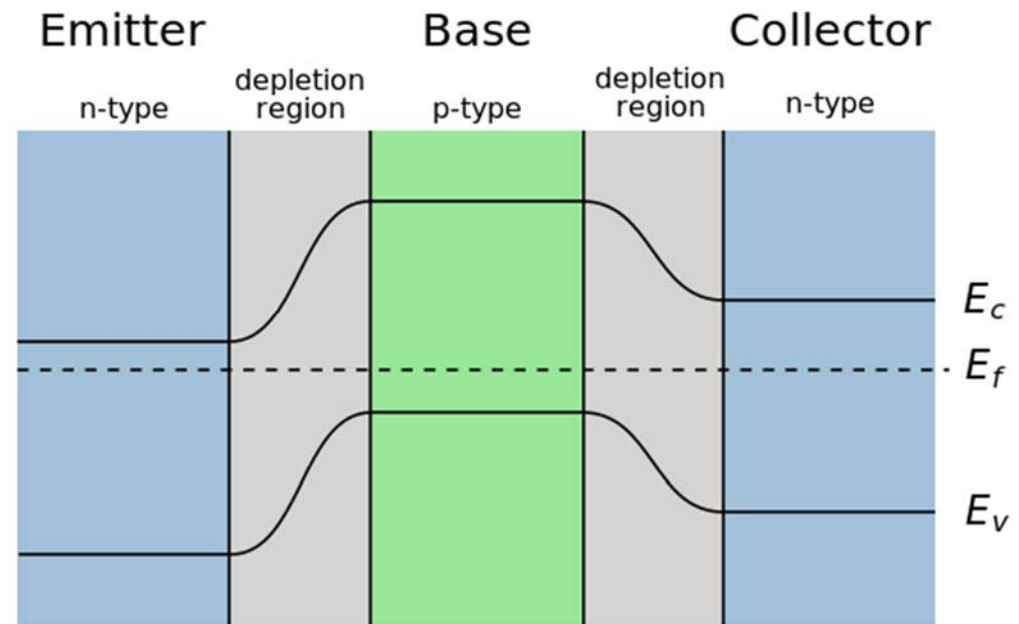


- $N_E \gg N_B > N_C$

- $W \ll L$

Diagrama de bandas para el BJT NPN

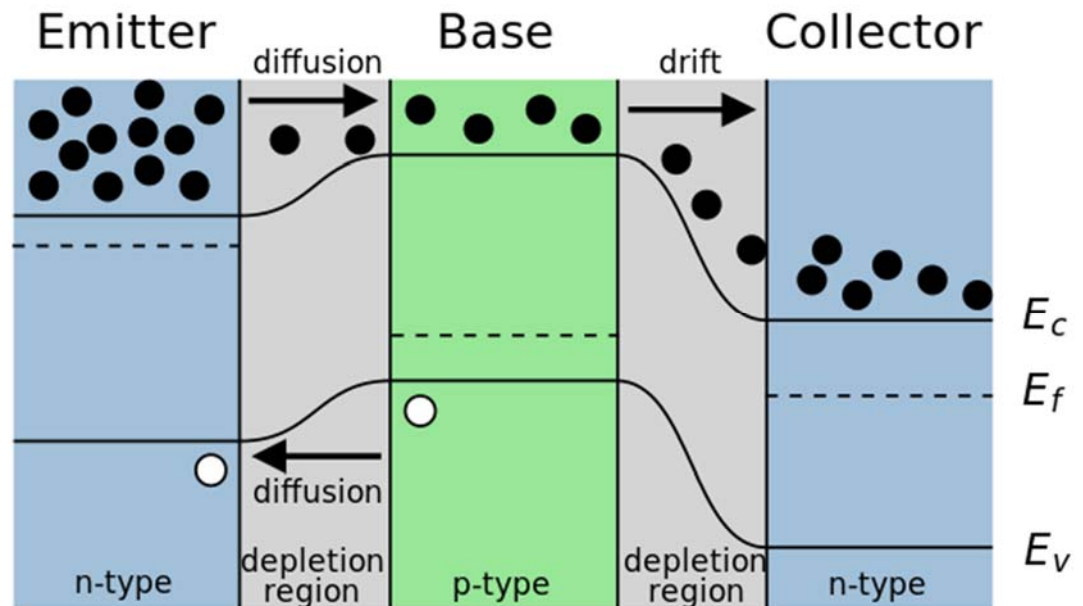
Sin tensión externa aplicada:



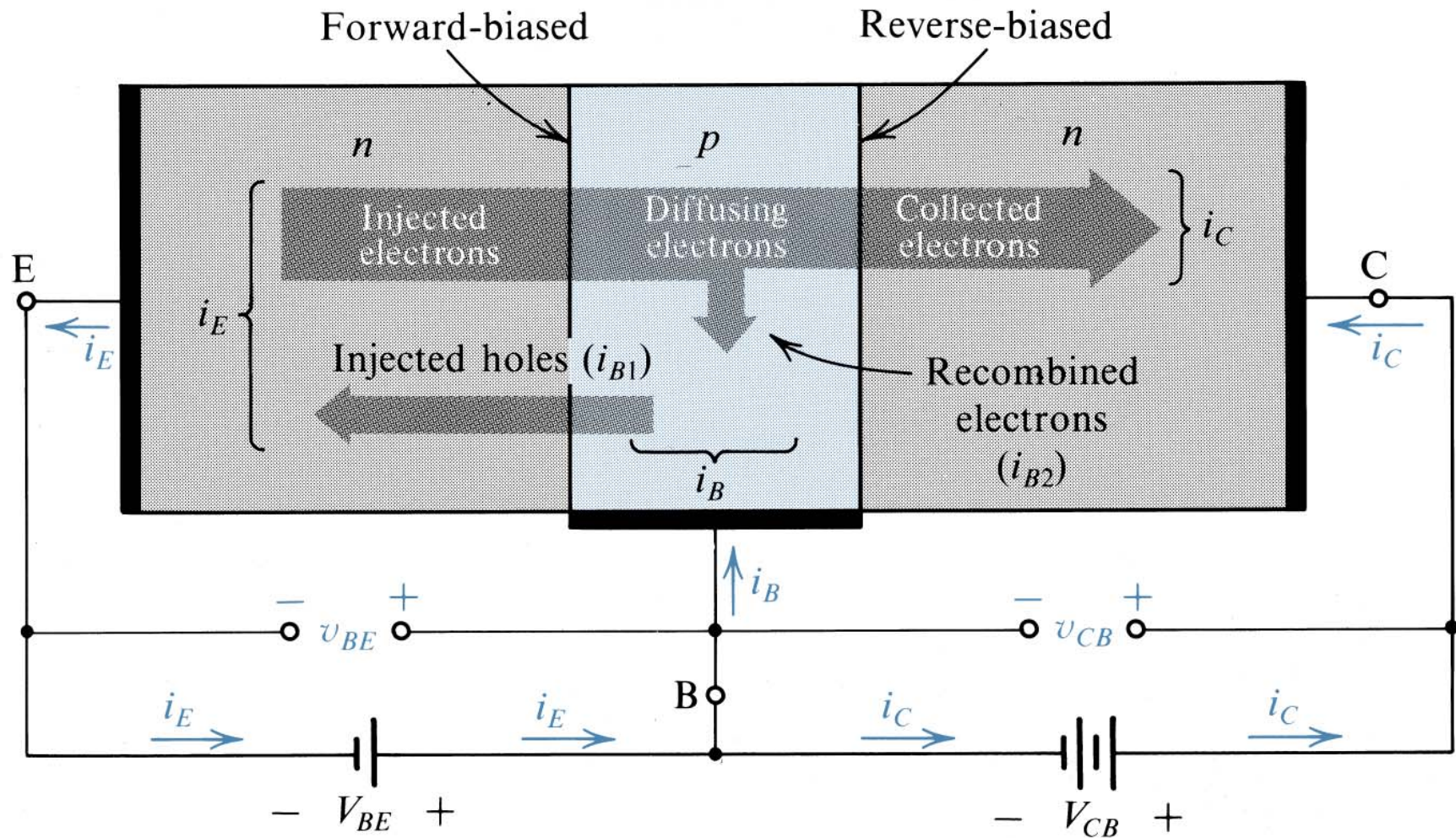
Polarizado en modo activo directo:

$$V_{BE} > 0 \quad (V_{BE} \approx V_{\gamma})$$

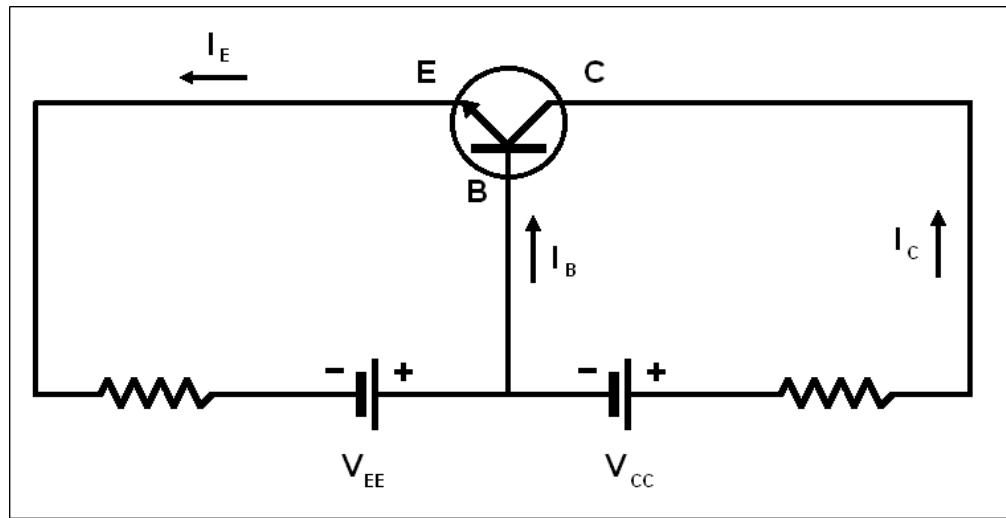
$$V_{BC} < 0$$



CORRIENTES EN EL TRANSISTOR NPN



Modo activo directo: corrientes



Unión BE en directa:

$$V_{BE} > 0 \Leftrightarrow V_{EE} > 0$$

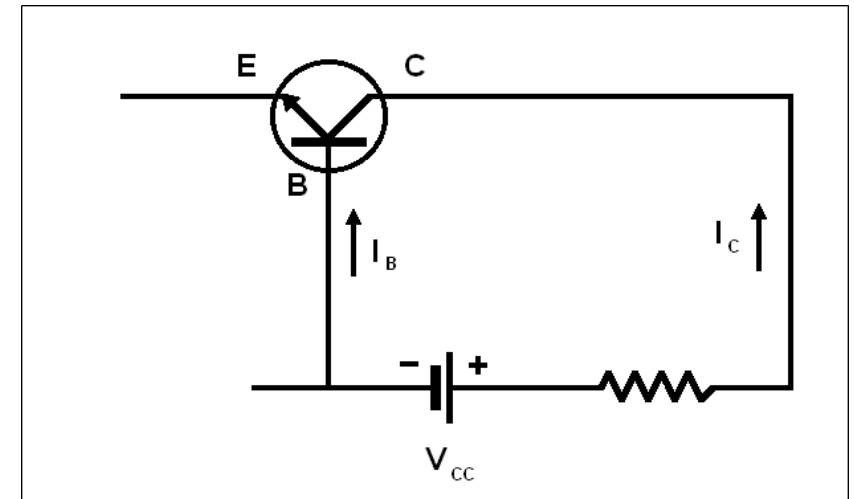
Unión BC en inversa:

$$V_{BC} < 0 \Leftrightarrow V_{CC} > 0$$

$$I_C = \alpha_F I_E$$

$$\alpha_F \equiv \frac{I_C}{I_E} = \frac{I_C}{I_B + I_C} = \frac{I_C / I_B}{1 + I_C / I_B} = \frac{\beta_F}{1 + \beta_F}$$

α_F : Ganancia de corriente en base común;

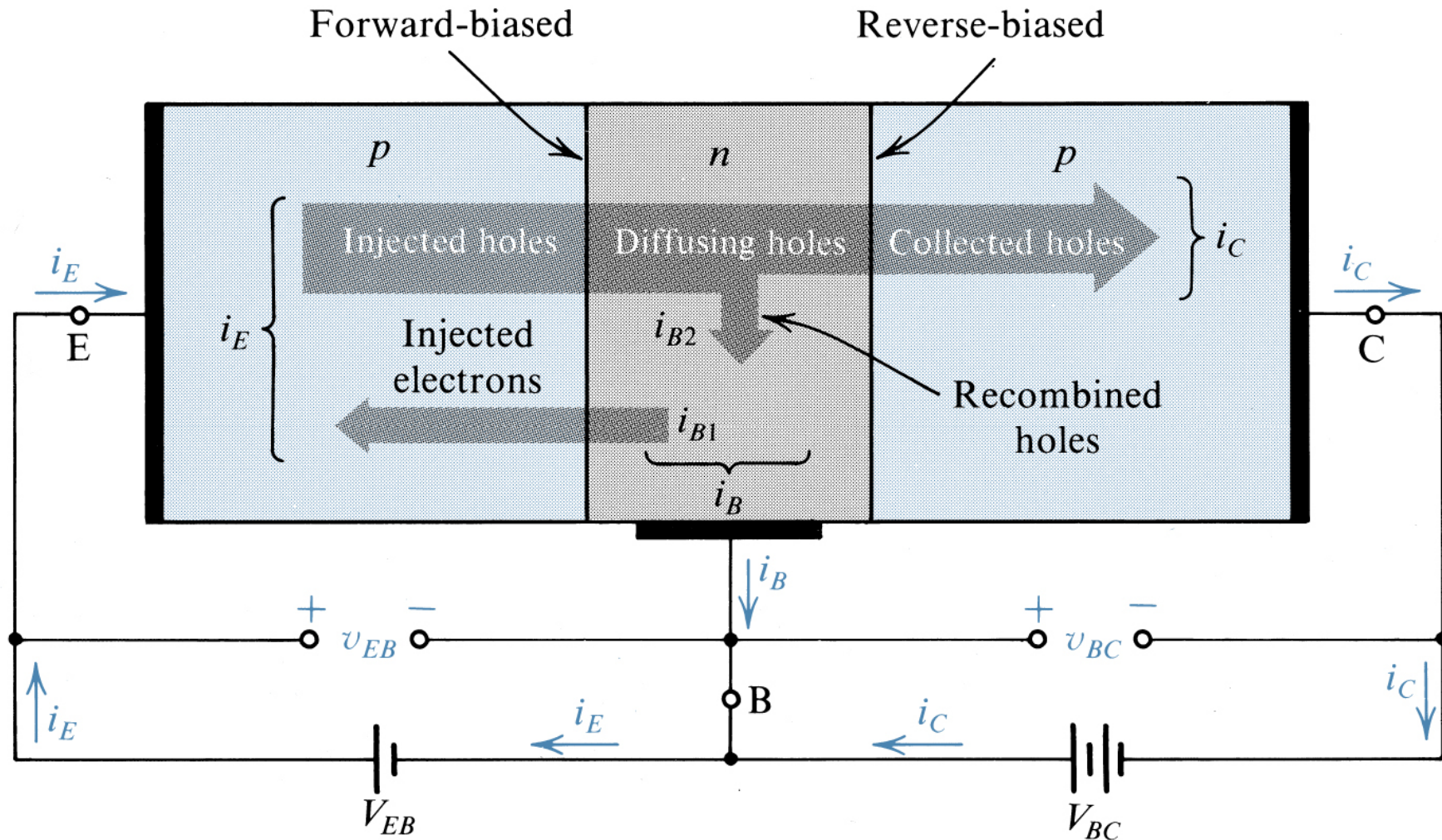


Ganancia de corriente en emisor común:

$$\beta_F \equiv \frac{I_C}{I_B};$$

$$\beta_F = \frac{\alpha_F}{1 - \alpha_F}$$

CORRIENTES EN UN TRANSISTOR PNP



Características I-V en configuración de base común

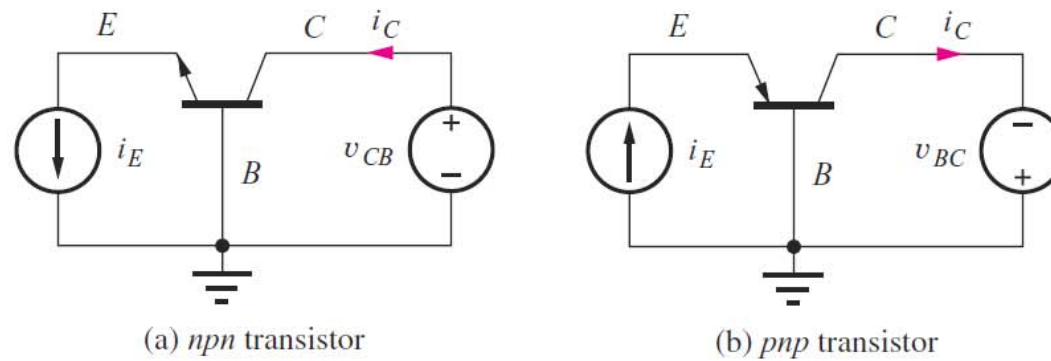


Figure 5.11 Circuits to determine common-base output characteristics.

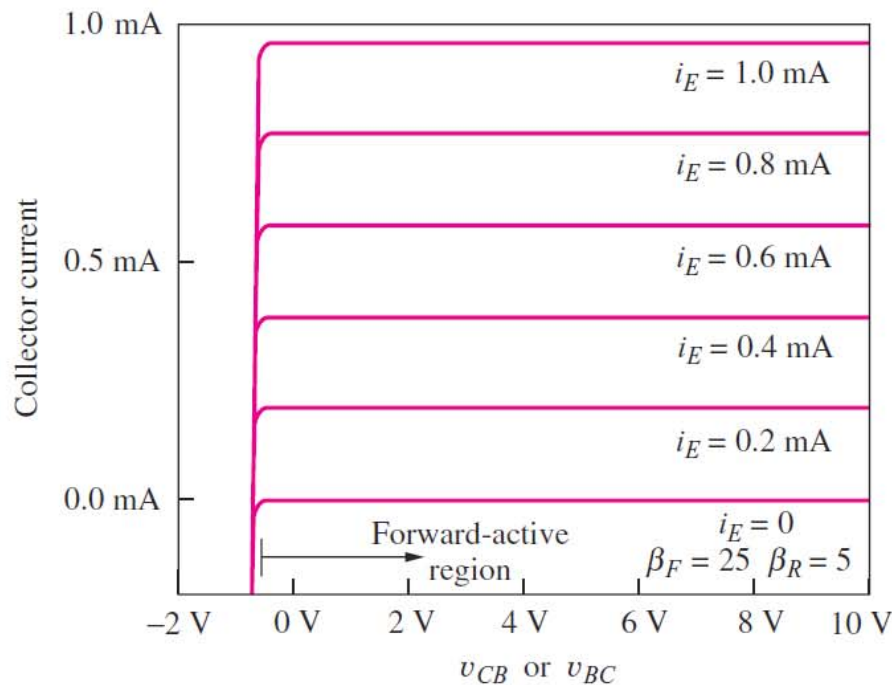


Figure 5.12 Common-base output characteristics for the bipolar transistor (i_C vs. v_{CB} for the *npn* transistor or i_C vs. v_{BC} for the *pnp* transistor).

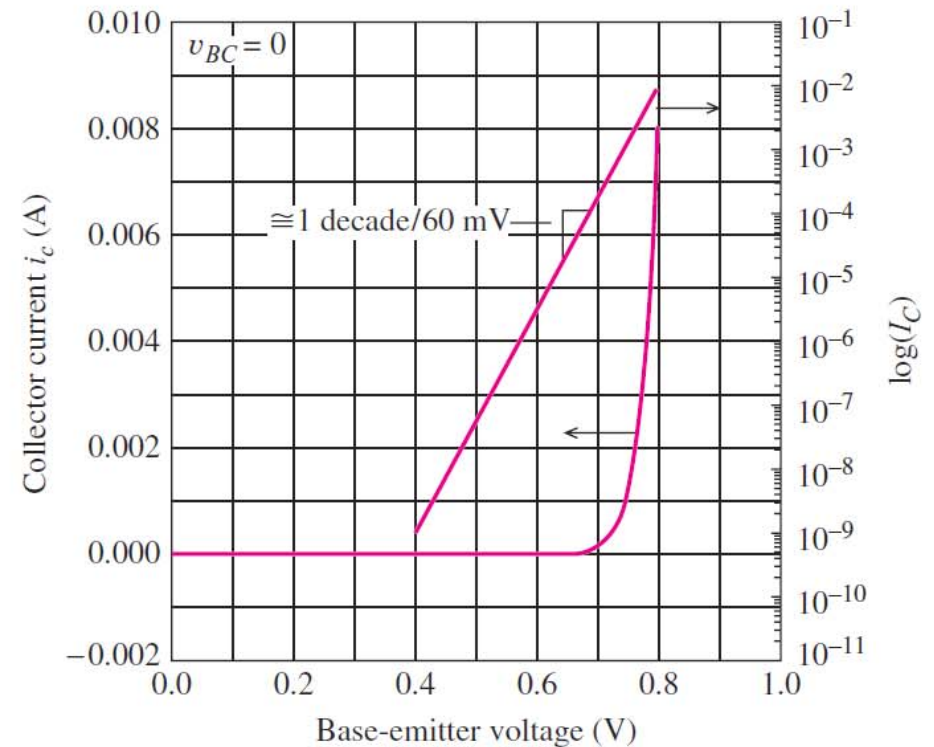


Figure 5.13 BJT transfer characteristic in the forward-active region.

Características I-V en configuración de emisor común

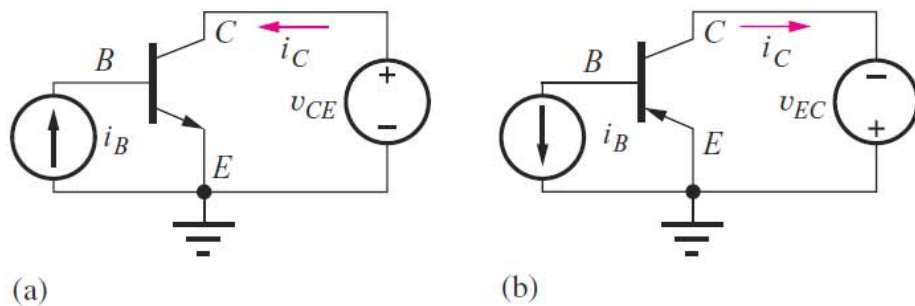


Figure 5.9 Circuits for determining common-emitter output characteristics: (a) *npn* transistor, (b) *pnp* transistor.

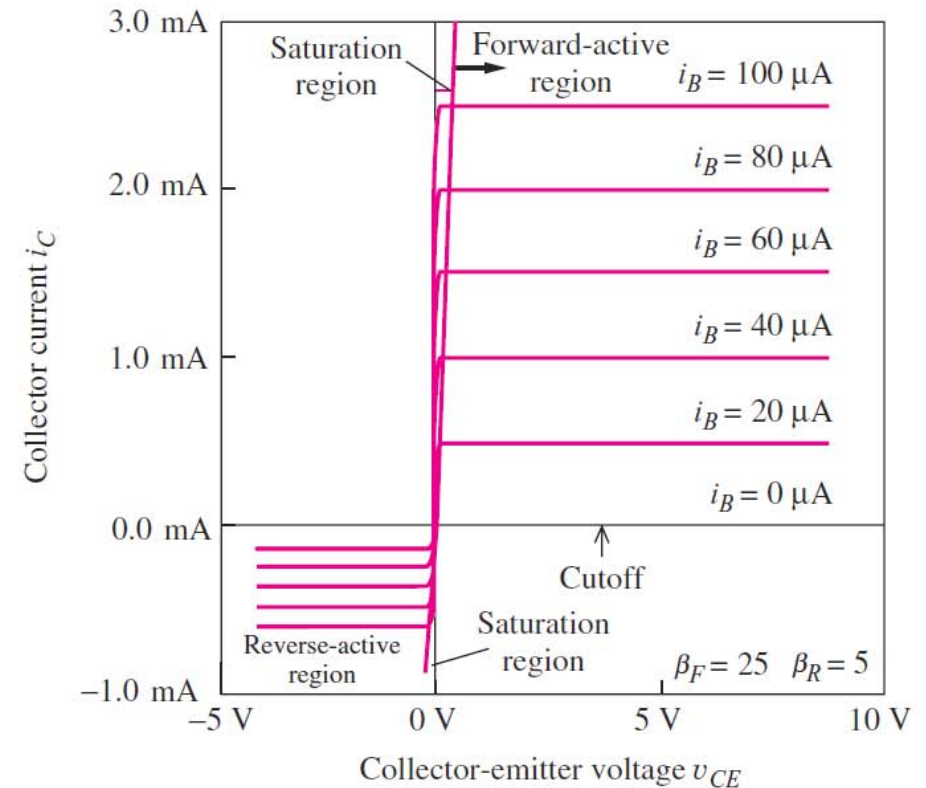
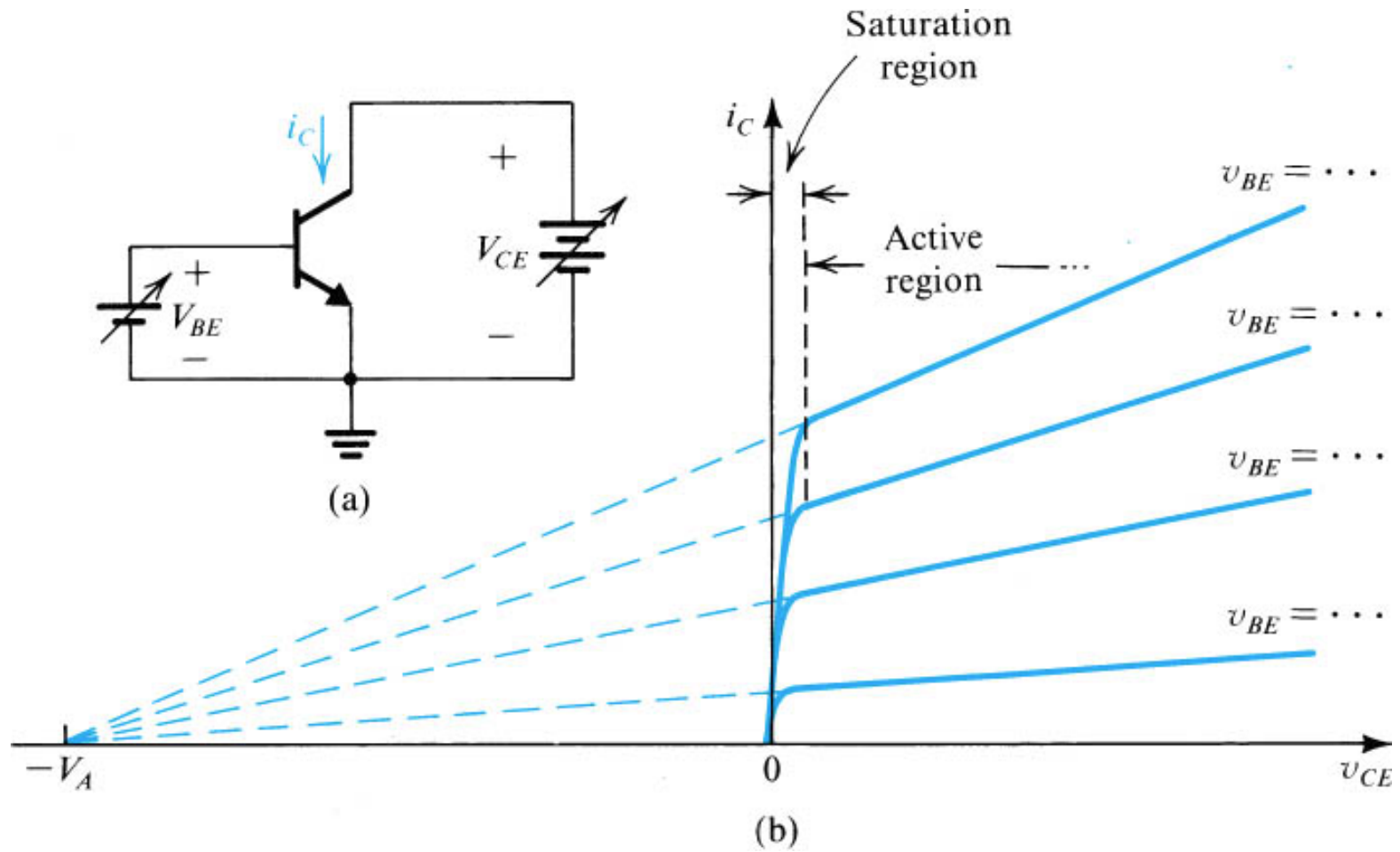
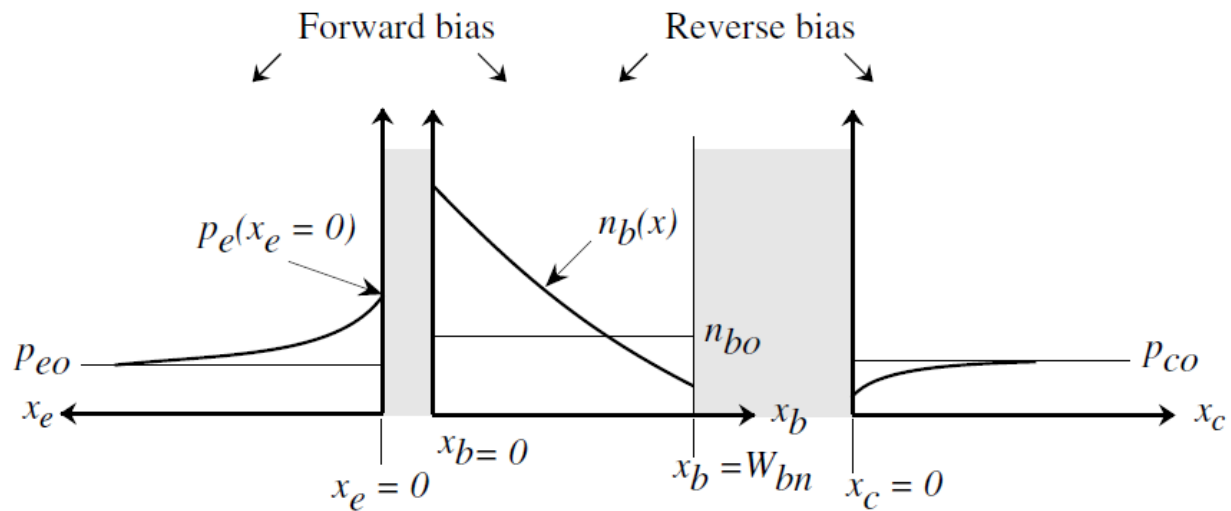
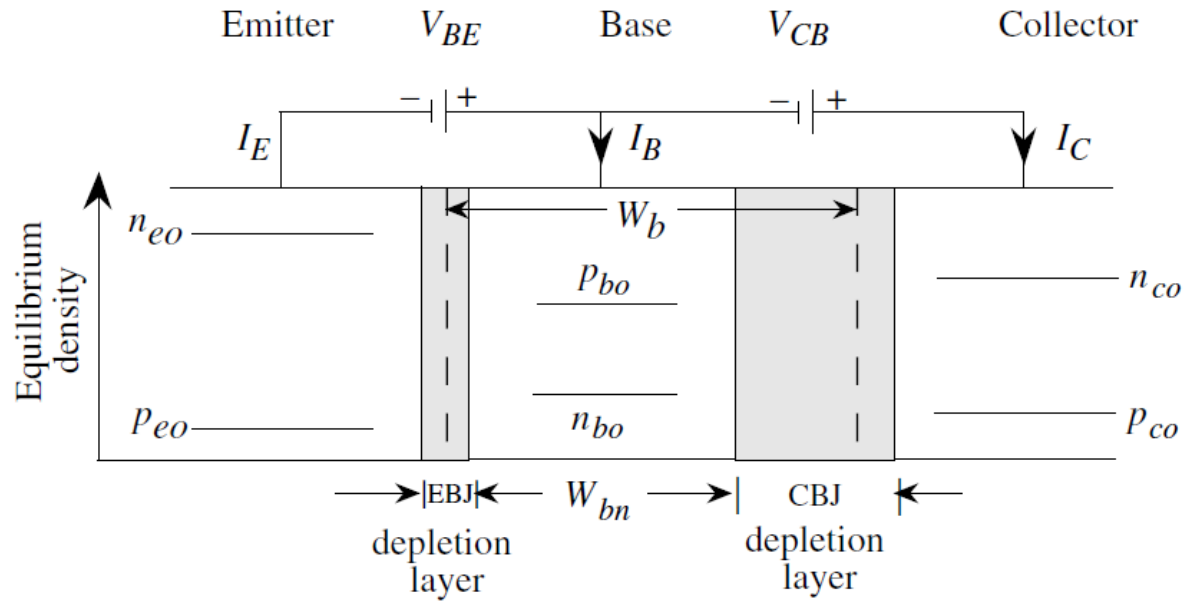


Figure 5.10 Common-emitter output characteristics for the bipolar transistor (i_C vs. v_{CE} for the *npn* transistor or i_C vs. v_{EC} for the *pnp* transistor).

EFFECTO EARLY



EFFECTO EARLY



Características I-V del transistor BJT NPN

- Configuración en base común:

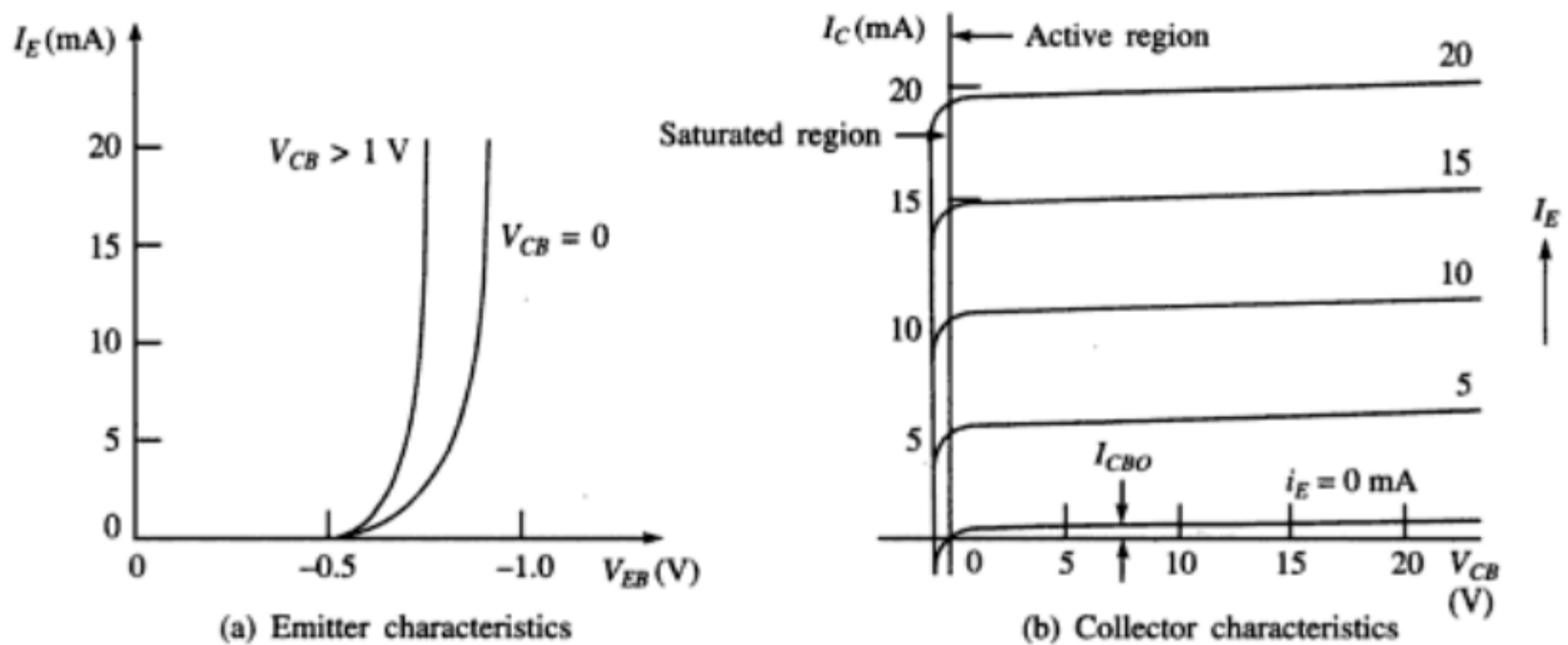


FIGURE 2.9 Common-base characteristics of an *npn* transistor.

Características I-V del transistor BJT NPN

- Configuración en emisor común:

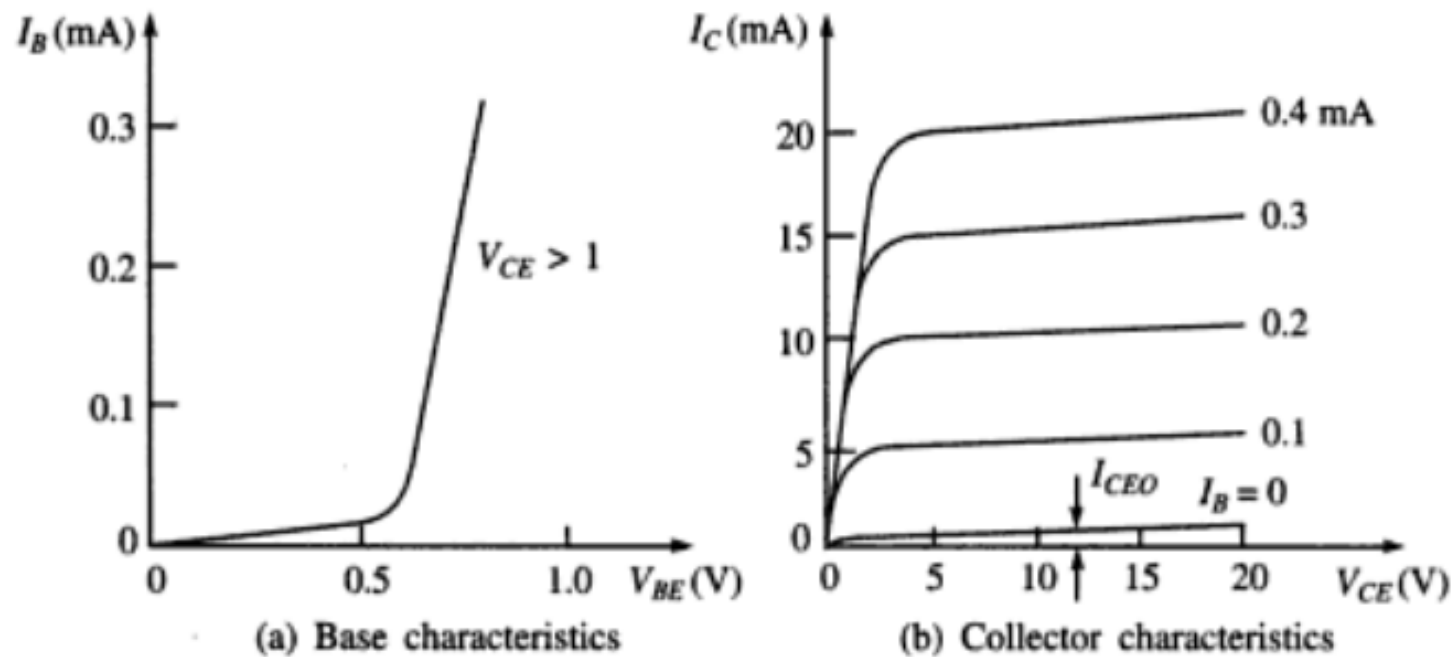


FIGURE 2.11 Common-emitter characteristics of an *npn* transistor.

Características I-V del transistor BJT NPN

- Configuración en emisor común: transistor de silicio

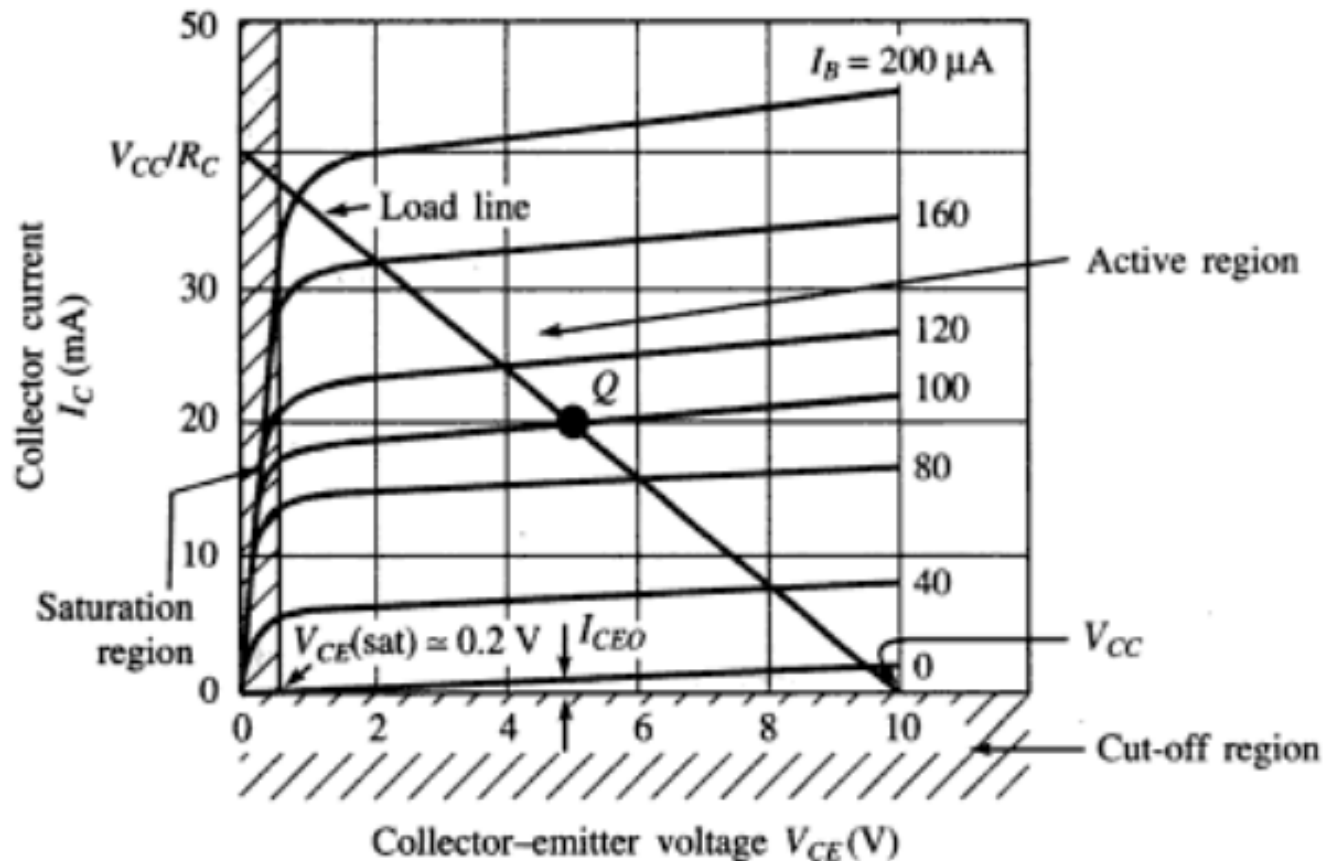


FIGURE 2.13 Common-emitter output characteristics of an *npn* silicon transistor.

REGIONES DE FUNCIONAMIENTO DEL TRANSISTOR

Modos de operación del transistor BJT:

Modo de operación	Polarización de la unión		Aplicación
	Base-Emisor	Base-Colector	
Activo directo	Directa	Inversa	Amplificación
Corte	Inversa	Inversa	Switch "OFF"
Saturación	Directa	Directa	Switch "ON"
Activa inversa	Inversa	Directa	No habitual

REGIONES DE FUNCIONAMIENTO DEL TRANSISTOR

- ACTIVA (DIRECTA):

$$\left. \begin{array}{l} V_{BE} > V_{\gamma} \\ V_{CB} > 0 \end{array} \right\}$$



$$I_C = \beta_F I_B; \quad \beta_F \gg 1; \quad V_{\gamma} \approx 0.6 \sim 0.7 \text{ V}$$

- (ACTIVA) INVERSA:

$$\left. \begin{array}{l} V_{BC} > V_{\gamma} \\ V_{BE} < 0 \end{array} \right\}$$



$$I_E = \beta_R I_B; \quad \beta_R \ll \beta_F$$

- SATURACIÓN:

$$\left. \begin{array}{l} V_{BE} > V_{\gamma} \\ V_{CB} < 0 \\ (V_{CB} \approx -0.5 \text{ V}) \end{array} \right\}$$



$$\left\{ \begin{array}{l} I_C \text{ no es función de } I_B; \quad I_C < \beta_F I_B \\ V_{CE} \approx 0.1 \sim 0.2 \text{ V} \end{array} \right.$$

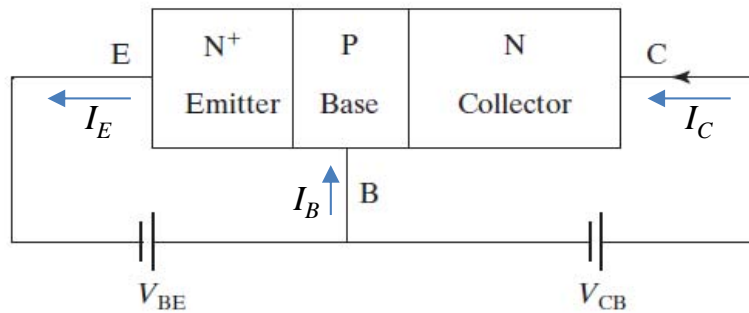
- CORTE:

$$\left. \begin{array}{l} V_{BE} < V_{\gamma} \\ V_{BC} < V_{\gamma} \end{array} \right\}$$

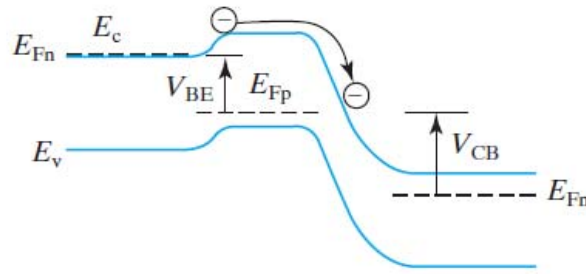


$$I_B = 0; \quad I_C = 0; \quad I_E = 0$$

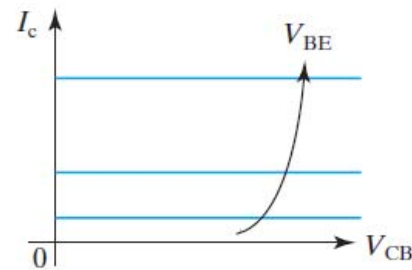
MODELO DE EBERS-MOLL (1)



(a)



(b)



(c)

La corriente de colector, I_C , está gobernada por las dos tensiones: V_{BE} y V_{CB} .

FIGURE 8-1 (a) Schematic NPN BJT and normal voltage polarities; (b) electron injection from emitter into base produces and determines I_C ; and (c) I_C is basically determined by V_{BE} and is insensitive to V_{CB} .

MODELO DE EBERS-MOLL (2)

Siendo: β_F : ganancia de corriente directa (colector - base)

β_R : ganancia de corriente inversa (emisor - base)

$I_S \equiv I_{C0}$: corriente inversa de saturación de colector

- Cuando $V_{BC} = 0$ y sólo actúa $V_{BE} > 0$:

$$I_C = I_S (e^{V_{BE}/V_T} - 1)$$

$$I_B = \frac{I_S}{\beta_F} (e^{V_{BE}/V_T} - 1)$$

- Invirtiendo los papeles de C y E, y considerando ahora que $V_{BE} = 0$ y sólo actúa $V_{BC} > 0$:

$$-I_E = I_S (e^{V_{BC}/V_T} - 1)$$

$$I_B = \frac{I_S}{\beta_R} (e^{V_{BC}/V_T} - 1)$$

$$I_C = I_E - I_B = -I_S \left(1 + \frac{1}{\beta_R}\right) (e^{V_{BC}/V_T} - 1)$$

MODELO DE EBERS-MOLL (3)

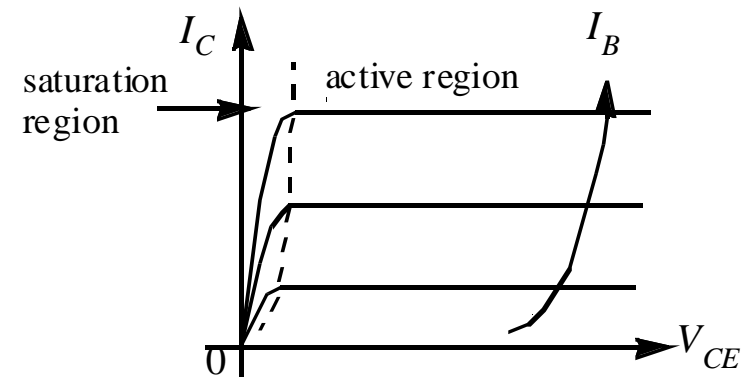
En el caso general, cuando ambas tensiones, V_{BE} y V_{BC} , actúan:

$$I_C = I_S (e^{V_{BE}/V_T} - 1) - I_S \left(1 + \frac{1}{\beta_R}\right) (e^{V_{BC}/V_T} - 1)$$

$$I_B = \frac{I_S}{\beta_F} (e^{V_{BE}/V_T} - 1) + \frac{I_S}{\beta_R} (e^{V_{BC}/V_T} - 1)$$

$$I_E = I_S \left(1 + \frac{1}{\beta_F}\right) (e^{V_{BE}/V_T} - 1) - I_S (e^{V_{BC}/V_T} - 1)$$

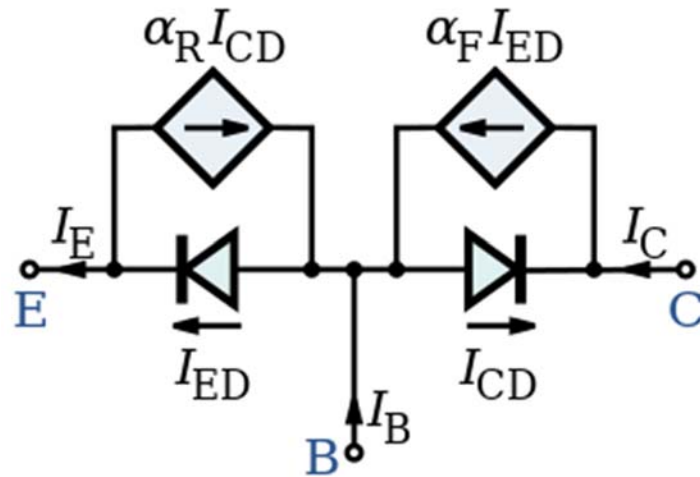
El modelo de Ebers-Moll describe ambas regiones de conducción, activa y de saturación:



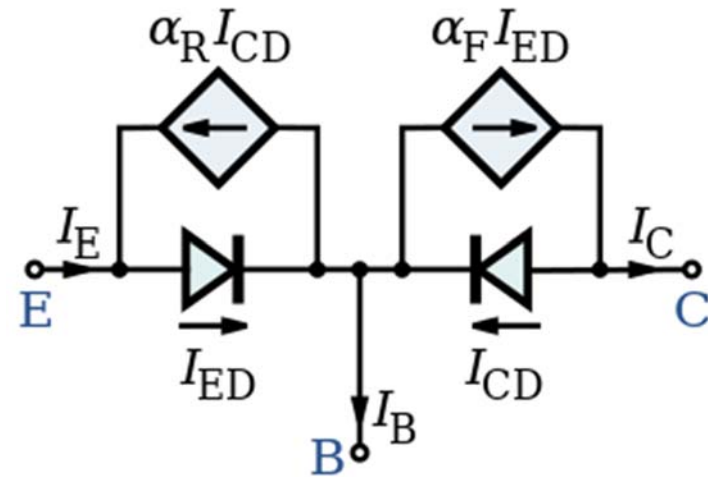
MODELO DE EBERS-MOLL (y 4)

Modelos esquemáticos:

NPN



PNP



Modelo aproximado para el modo activo directo (NPN):

