Semiconductor Devices

THIRD EDITION

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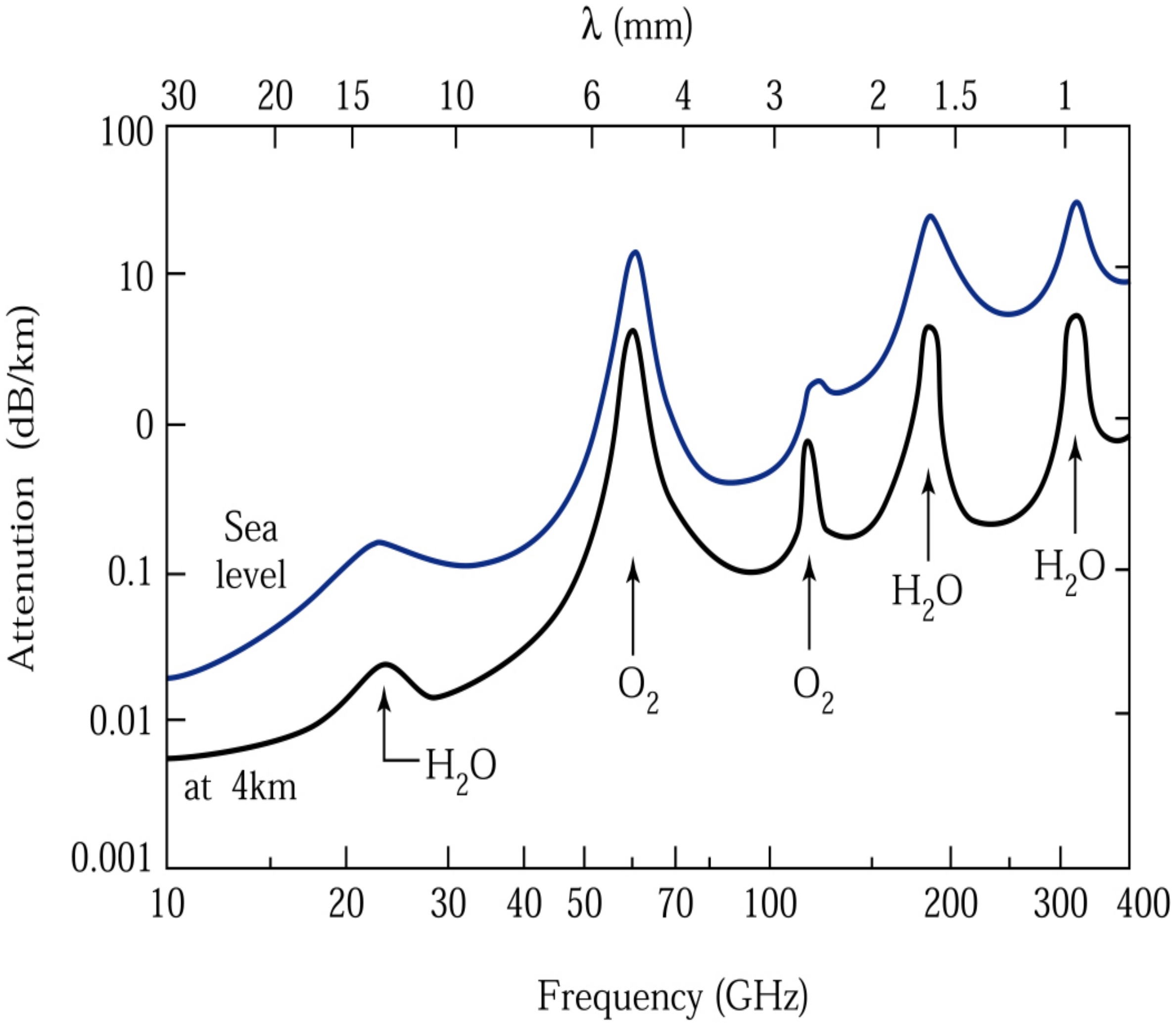
Chapter 8

Microwave Diodes, Quantum-Effect and Hot-Electron Devices

TABLE 1 IEEE MICROWAVE FREQUENCY BANDS

Designation	Frequency range (GHz)	Wavelength (cm)
VHF	0.1– 0.3	300.00–100.00
UHF	0.3–1.0	100.00–30.00
L band	1.0–2.0	30.00–15.00
S band	2.0–4.0	15.00–7.50
C band	4.0–8.0	7.50–3.75
X band	8.0–13.0	3.75–2.31
Ku band	13.0–18.0	2.31–1.67
K band	18.0–28.0	1.67–1.07
Ka band	28.0–40.0	1.07–0.75
Millimeter	30.0–300.0	1.00–0.10
Submillimeter	300.0–3000.0	0.10–0.01

Table 8.1

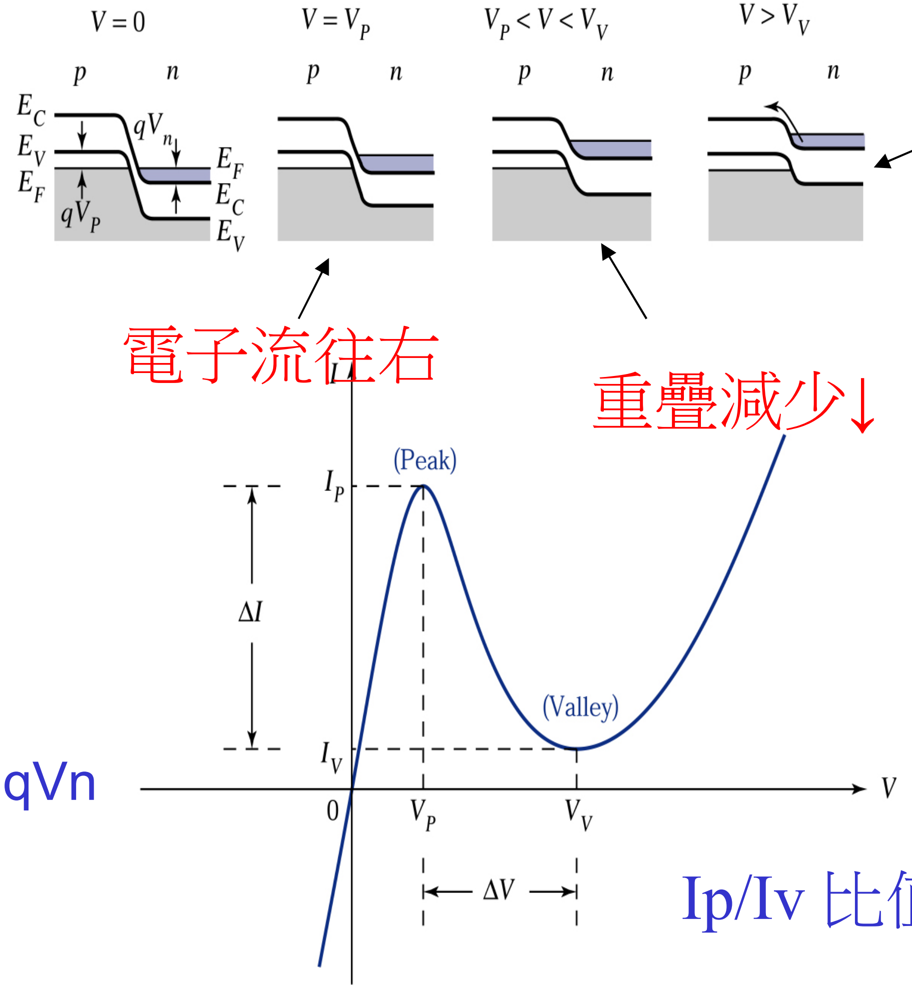


Absorption min. are at 35, 94, 140, and 220 GHz

Average atmosphere absorption of millimeter waves.[4] The upper curve is at the sea level; the lower curve is at 4 km above the sea level.

重疊↑

thermal



電子流往右

重疊減少↓

Degenerate:
very heavy doping

Degeneracy: qVp, qVn

Ip/Iv 比值是優劣指標

Figure 8.1. Static current-voltage characteristics of a typical tunnel diode. I_P and V_P are the peak current and peak voltage, respectively. I_V and V_V are the valley current and valley voltage, respectively. The upper figures show the band diagrams of the device at different bias voltages.

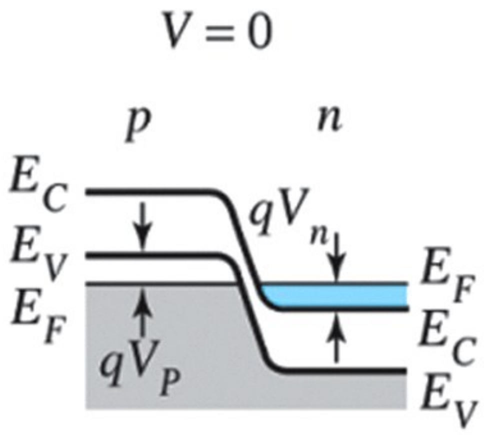


Figure 8.1 part 1

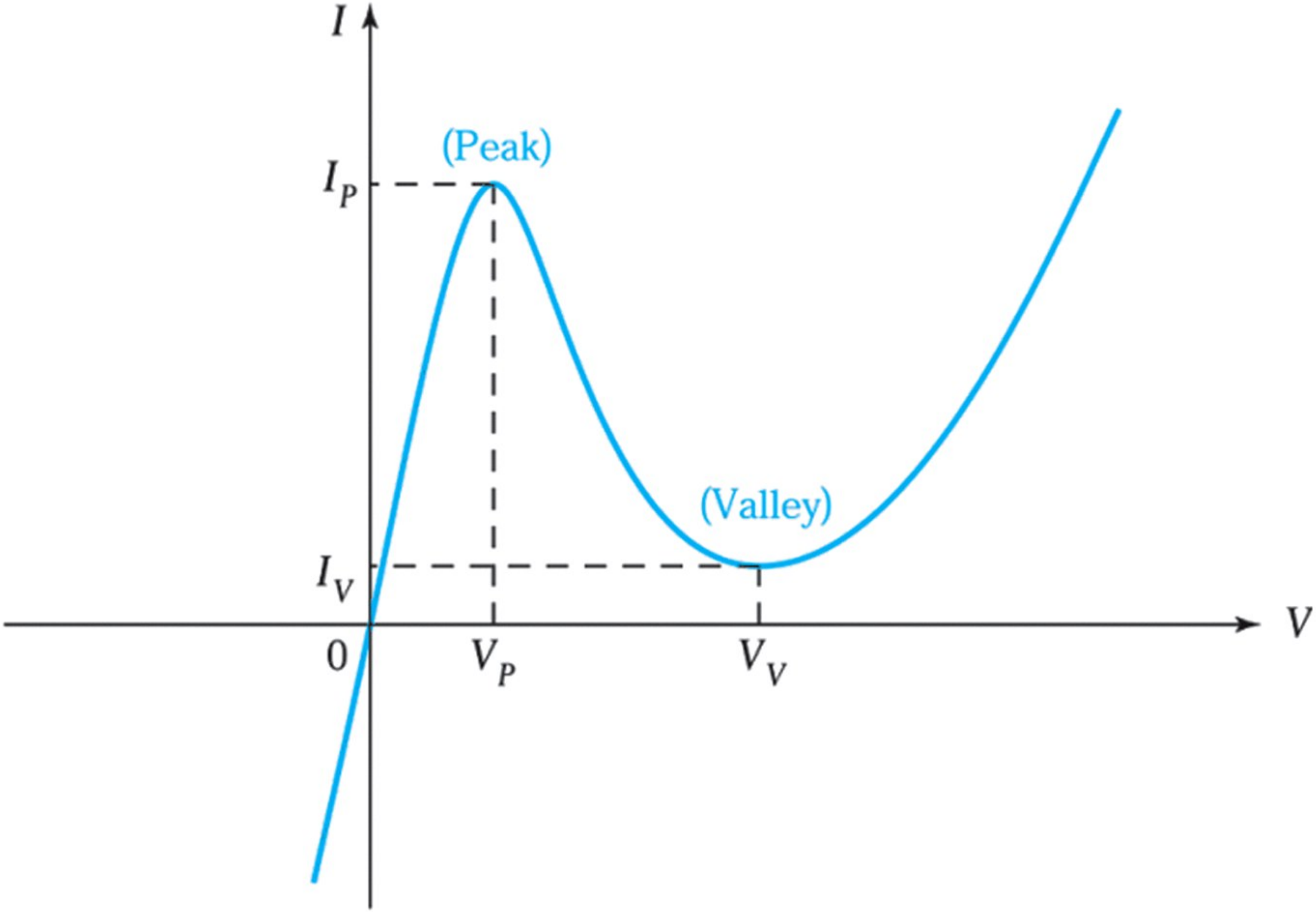
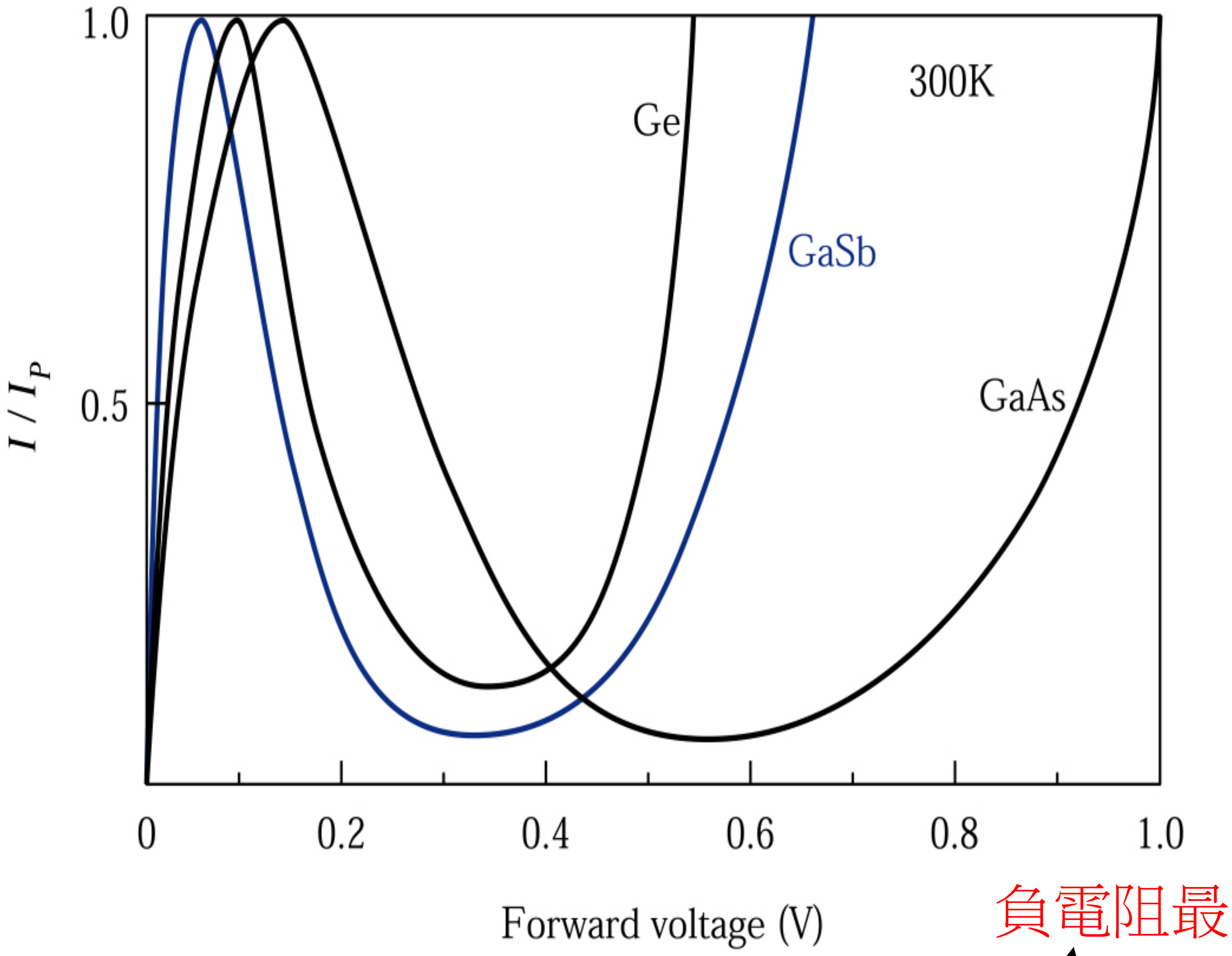


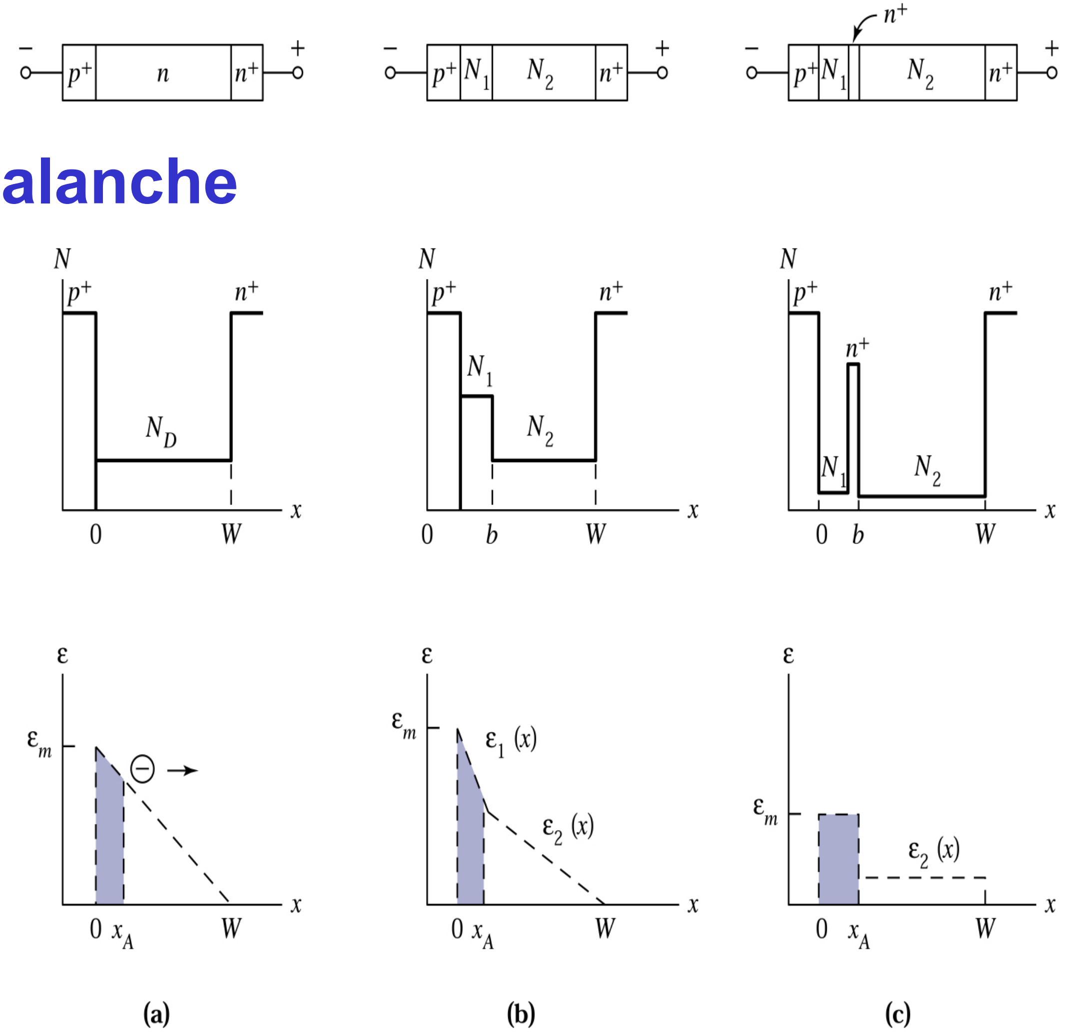
Figure 8.1 part 2



負電阻最大,best

Figure 8.2. Typical current-voltage characteristics of Ge, GaSb, and GaAs tunnel diodes at room temperature.

IMPATT:
Impact Ionization Avalanche Transit-Time



>30GHz

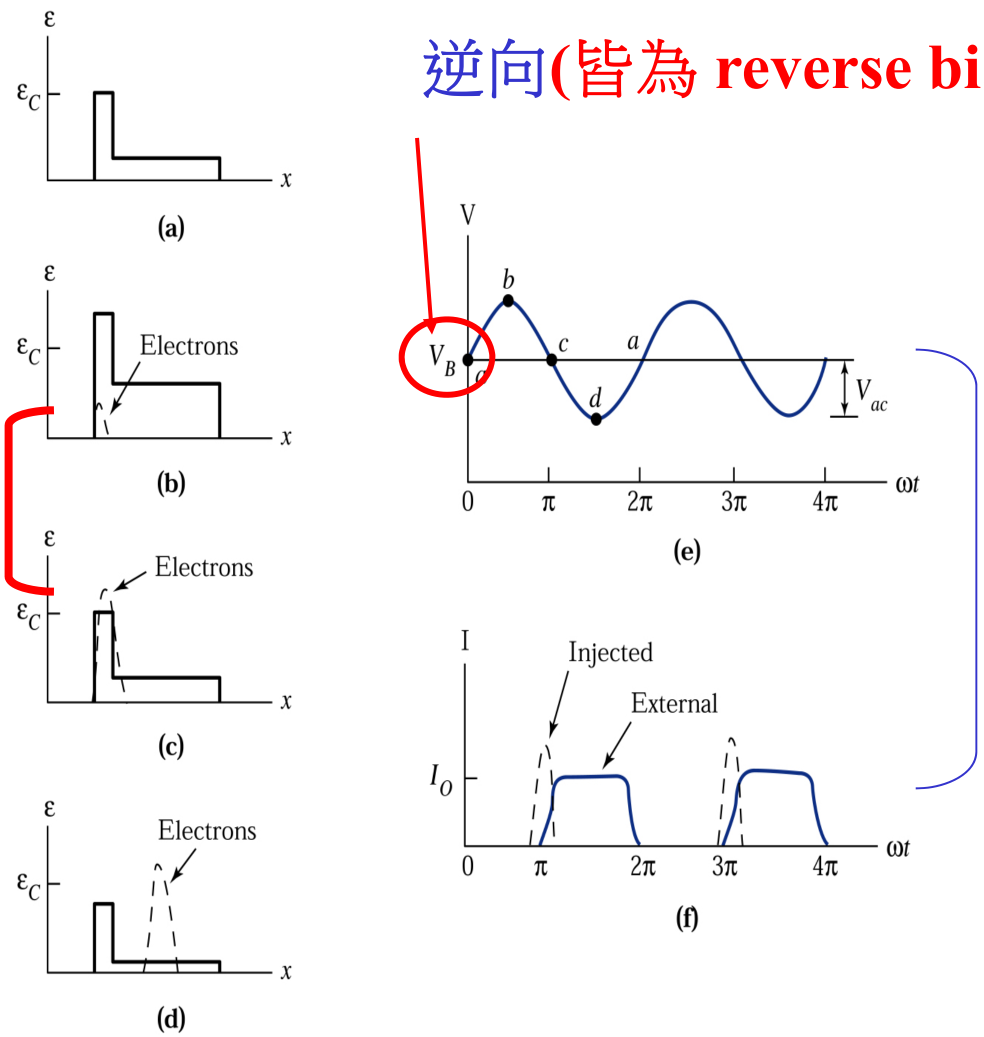
High noise

Figure 8.3. Doping profiles and electric-field distributions at avalanche breakdown of three single-drift IMPATT diodes: (*a*) one-sided abrupt *p-n* junction; (*b*) hi-lo structure; and (*c*) lo-hi-lo structure.

工作原理

由avalanche
變大

逆向(皆為 reverse bias)



V↓時, I↑.
所以負電阻.

Figure 8.4. Field distributions and generated-carrier densities of an IMPATT diode during an ac cycle at four intervals of time (*a*-*d*); (*e*) the ac voltage, and (*f*) the injected and external current.[7]

Transfer-electron device (TED)

Domain formation

(b) Small domain grow to (c) mature domain

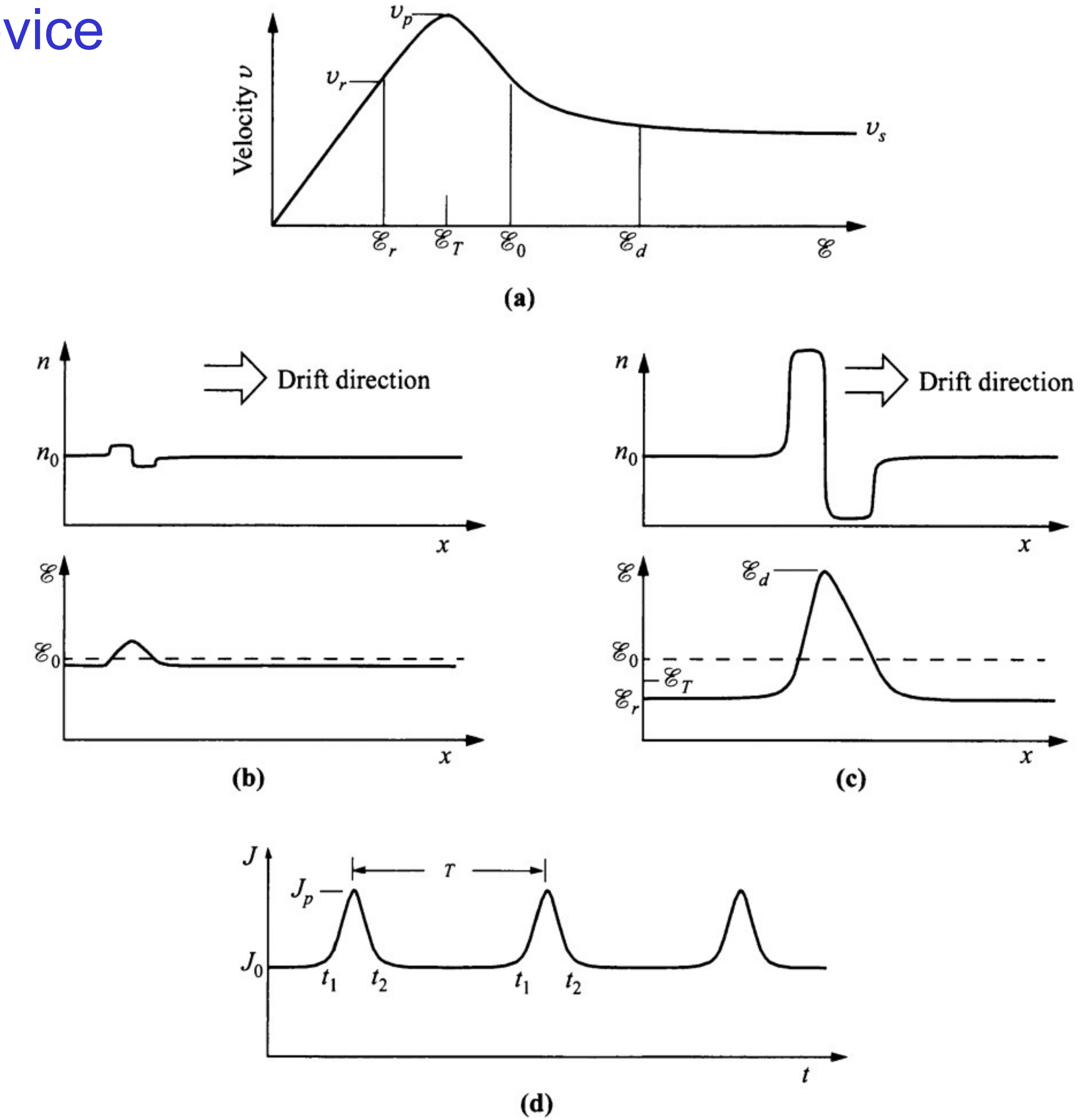
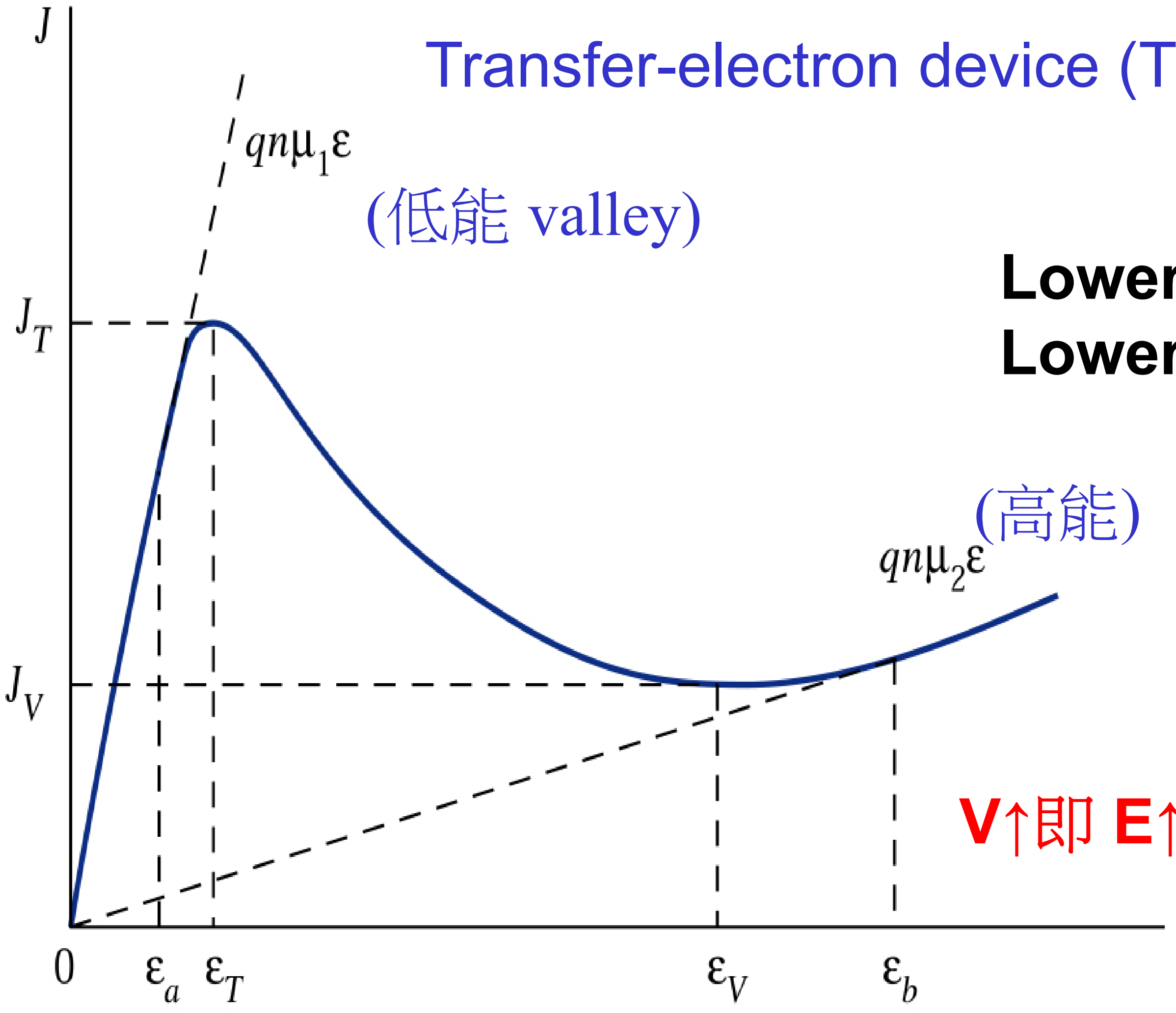


Figure 8.5

Transfer-electron device (TED)



(低能 valley)

(高能)

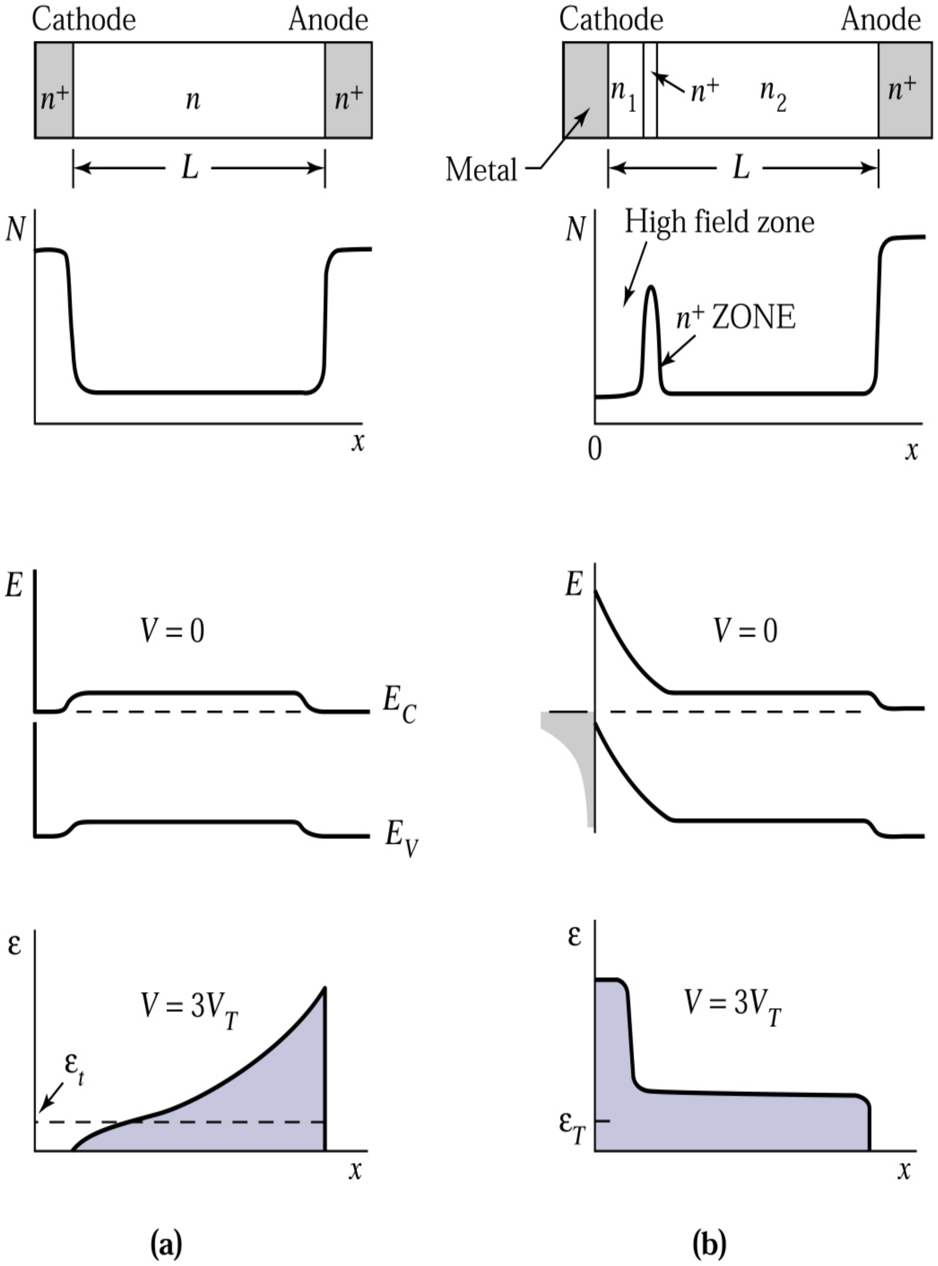
Lower power
Lower noise

V↑即 E↑得 i↓

Vd↓

The current versus electric-field characteristic of a two-valley semiconductor. ε_T is the threshold field and ε_V is the valley field.

Figure 8.6. Two cathode contacts for transferred-electron devices (TEDs) (*a*) Ohmic contact and (*b*) two-zone Schottky barrier contact.



Similar to IMPATT

Figure 8.7.
Numerical simulation of the time-dependant behavior of a cathode-nucleated TED for the transit-time domain mode.[11]

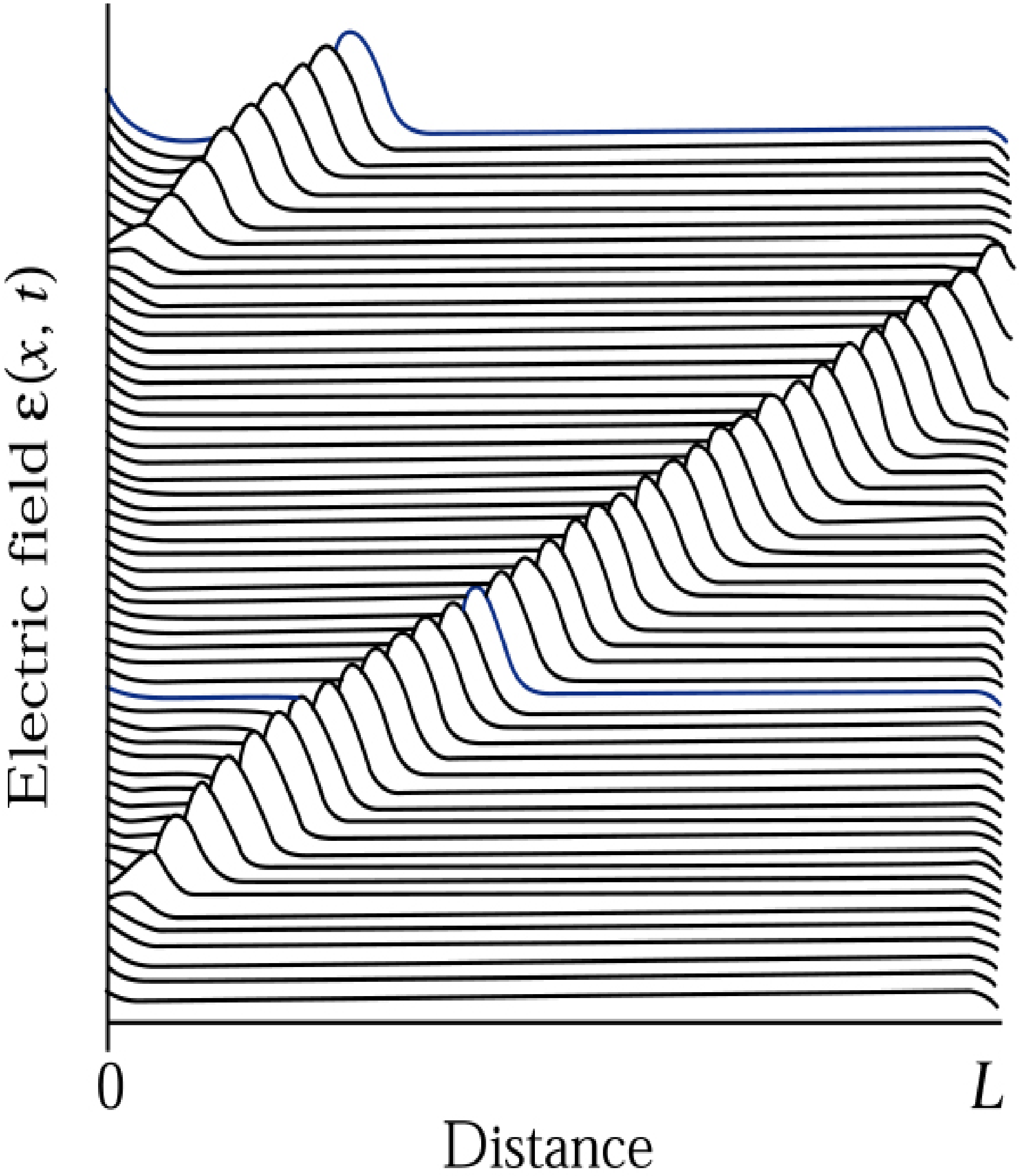
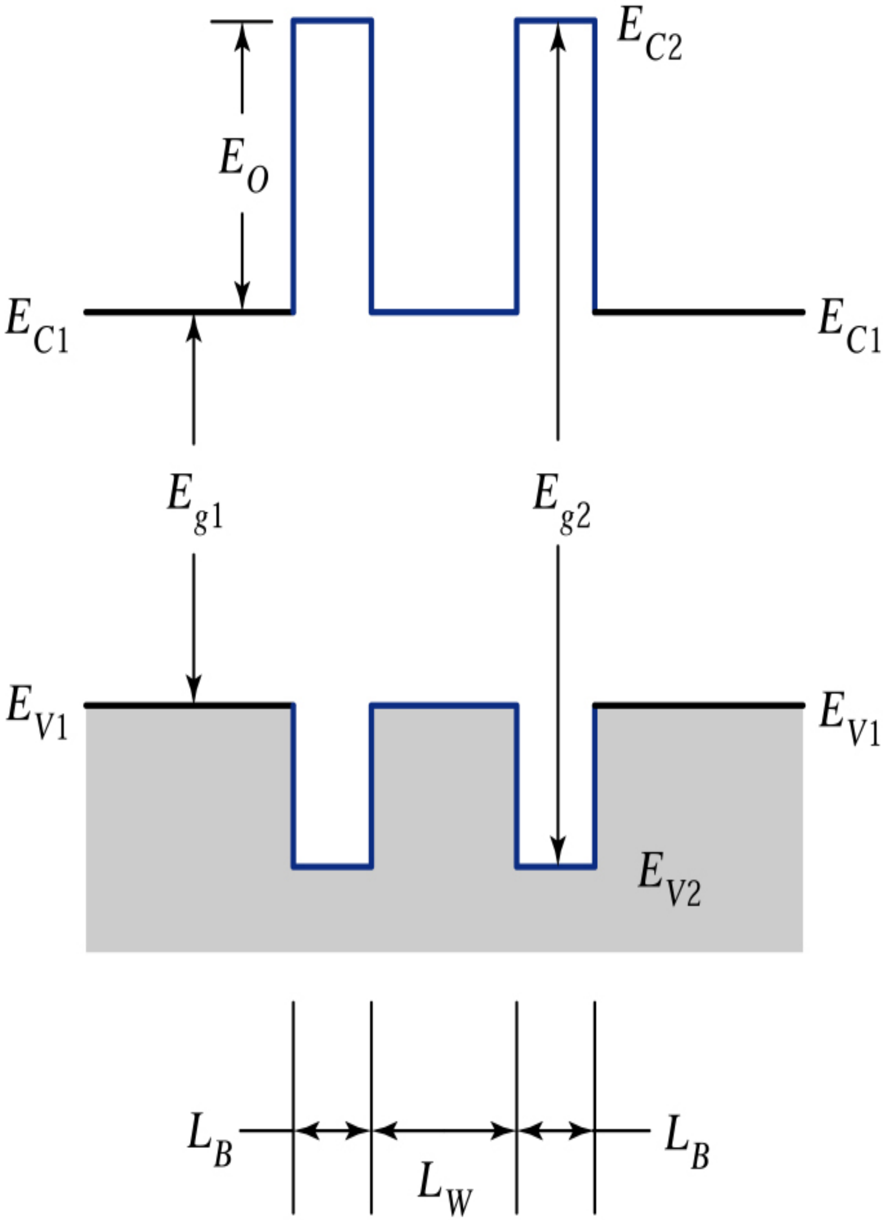


Figure 8.8.
Band diagram of a
resonant-tunneling diode.



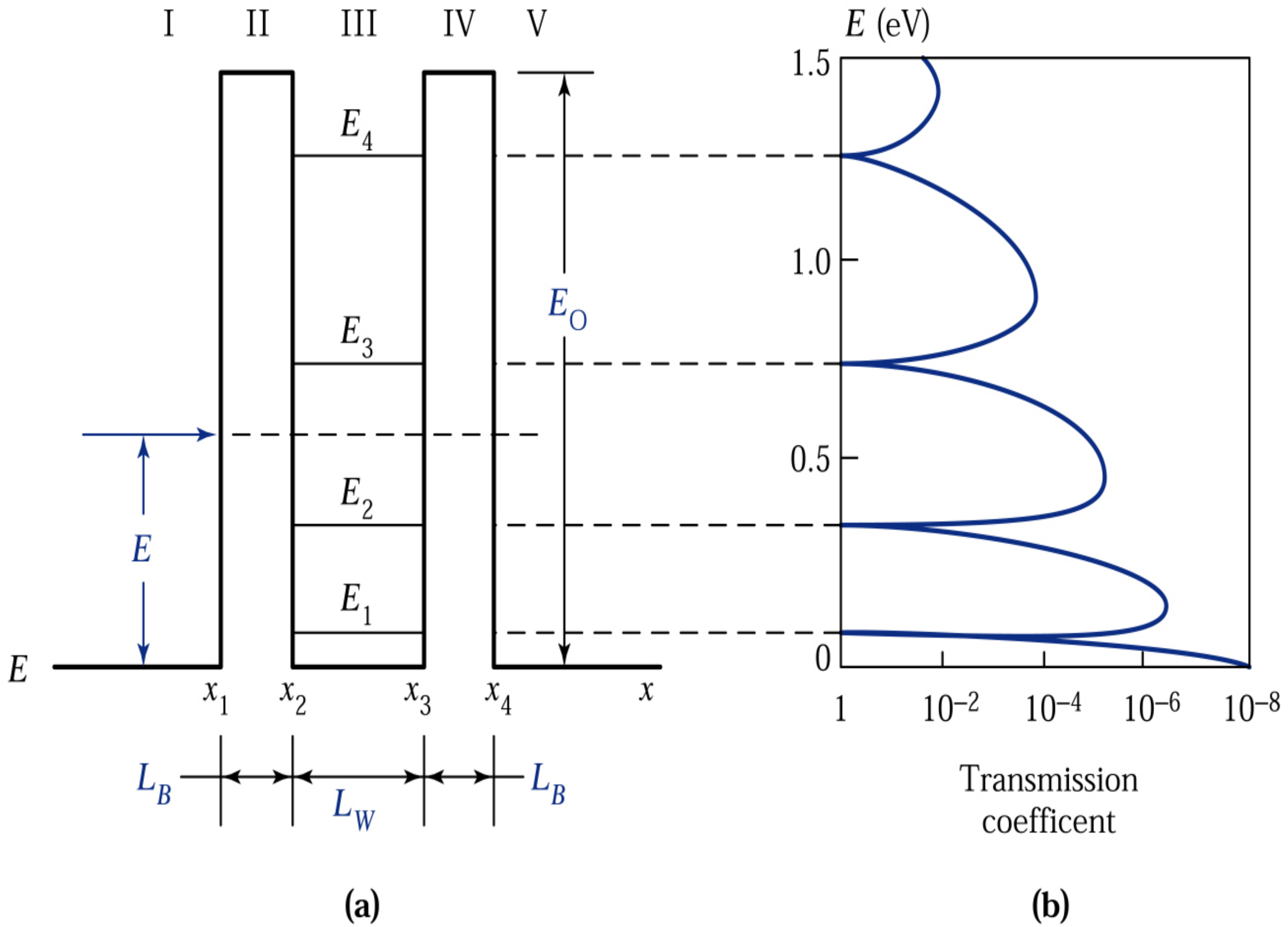
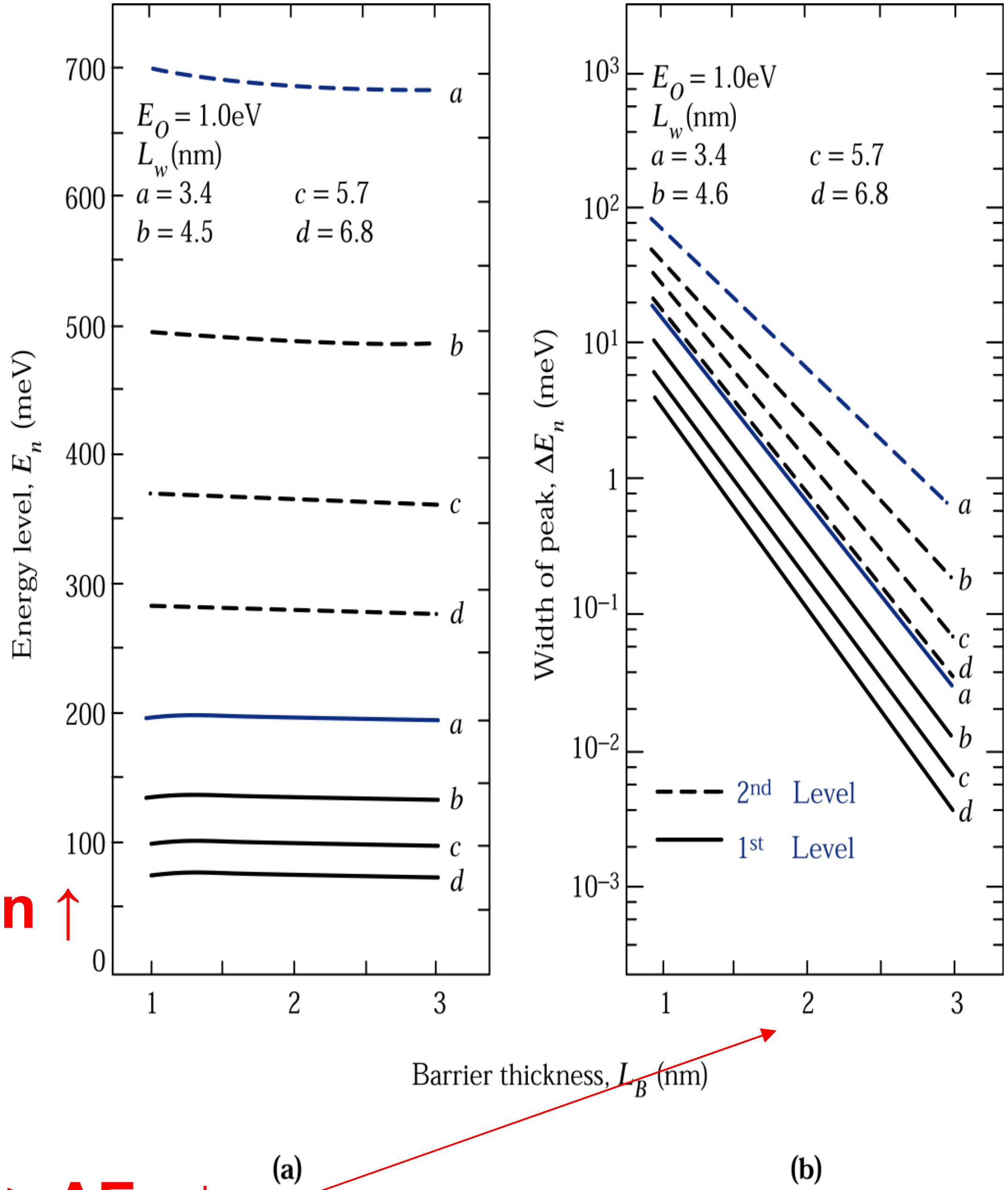


Figure 8.9. (*a*) Schematic illustration of AlAs/GaAs/AlAs double-barrier structure with a **2.5 nm barrier and a 7 nm well**. (*b*) Transmission coefficient versus electron energy for the structure.

Figure 8.10.
(*a*) Calculated energy of electrons at which the transmission coefficient shows the resonant peak in an AlAs/GaAs/AlAs structure as a function of barrier thickness for various well thicknesses. (*b*) Full width at half maximum of the transmission coefficient versus barrier thickness for the first and second resonant peak.[13]



Well thickness Lw ↓ => En ↑

Barrier thickness LB ↑ => ΔEn ↓

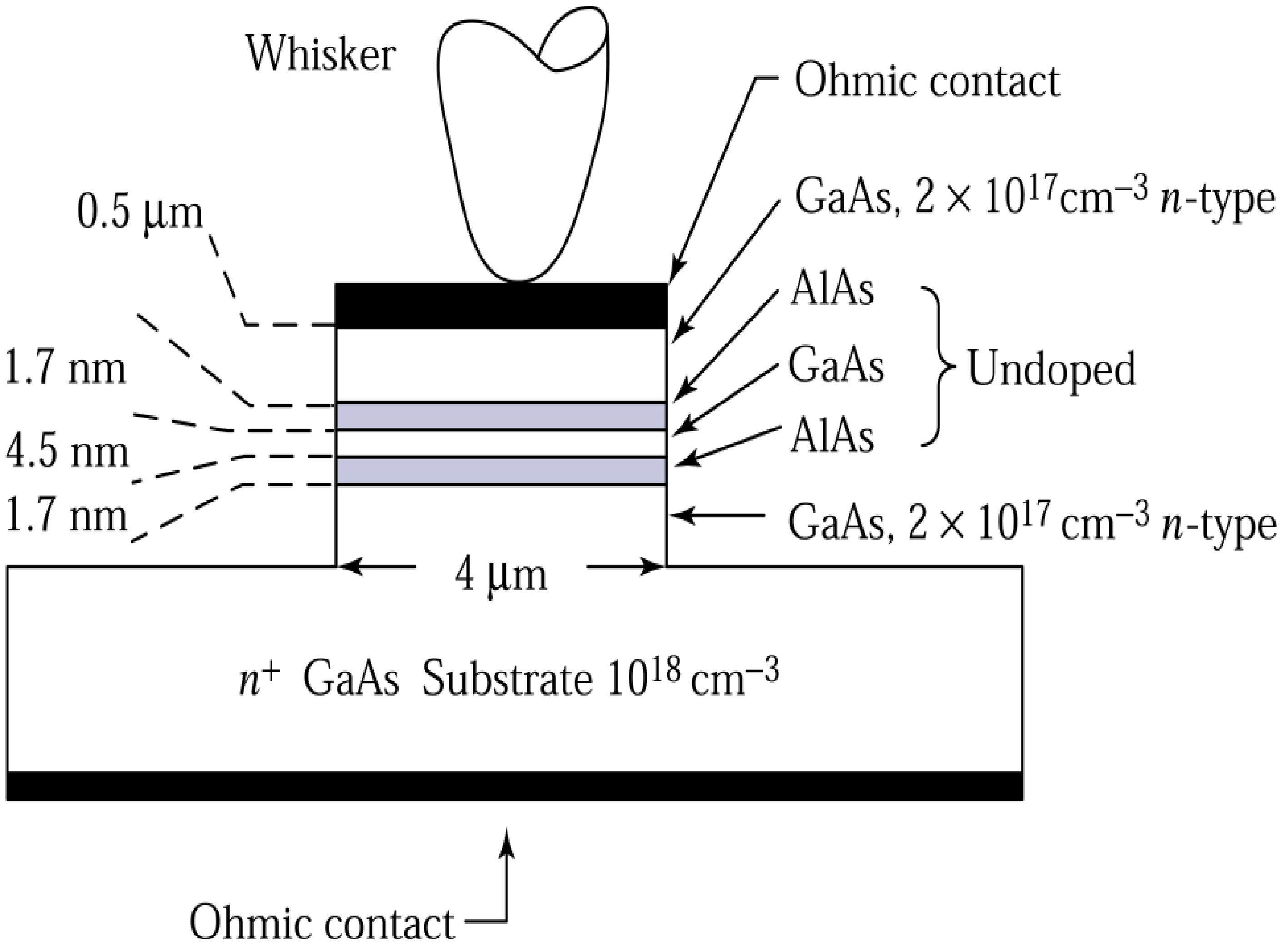
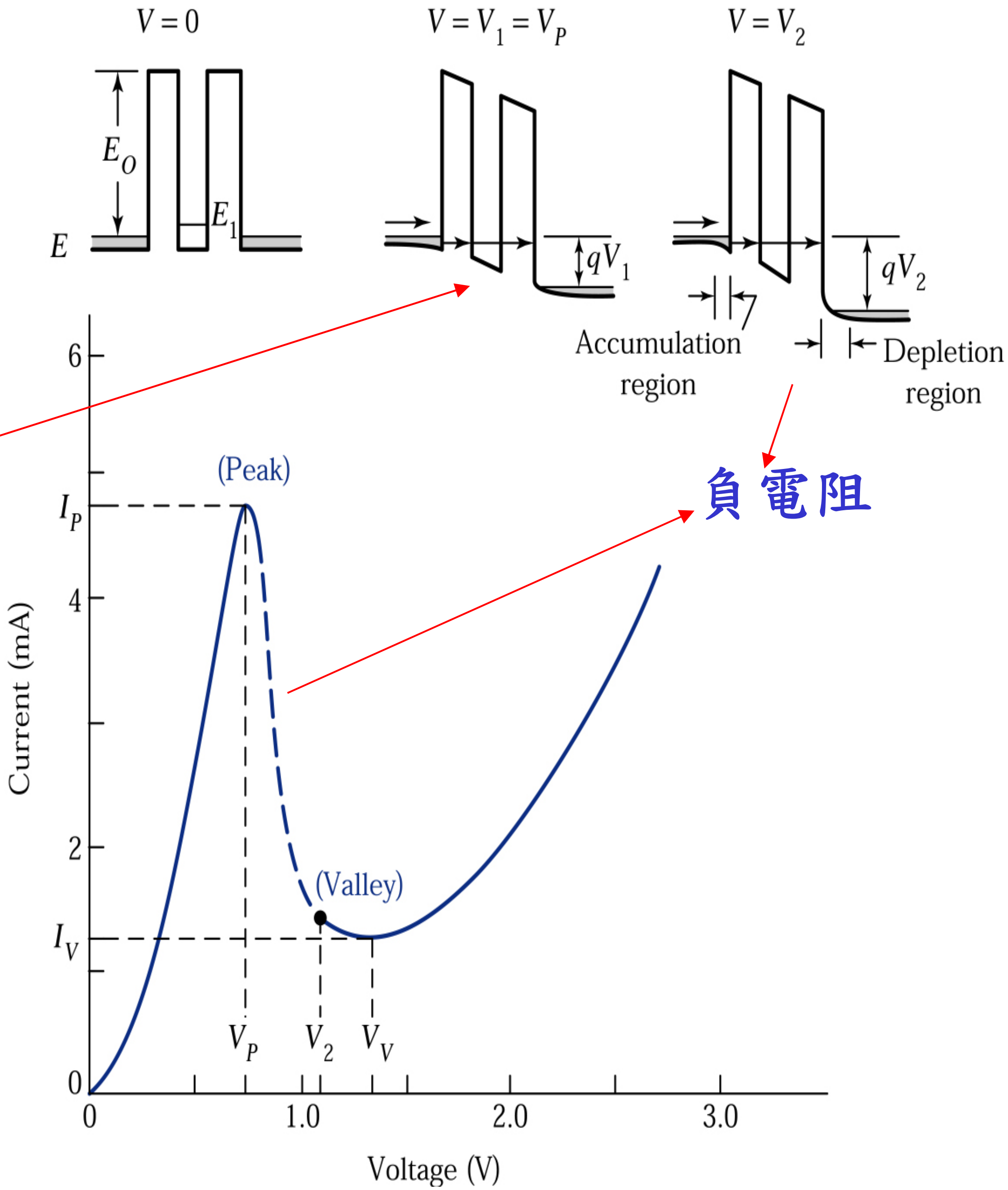


Figure 8.11. A mesa-type resonant tunneling diode.

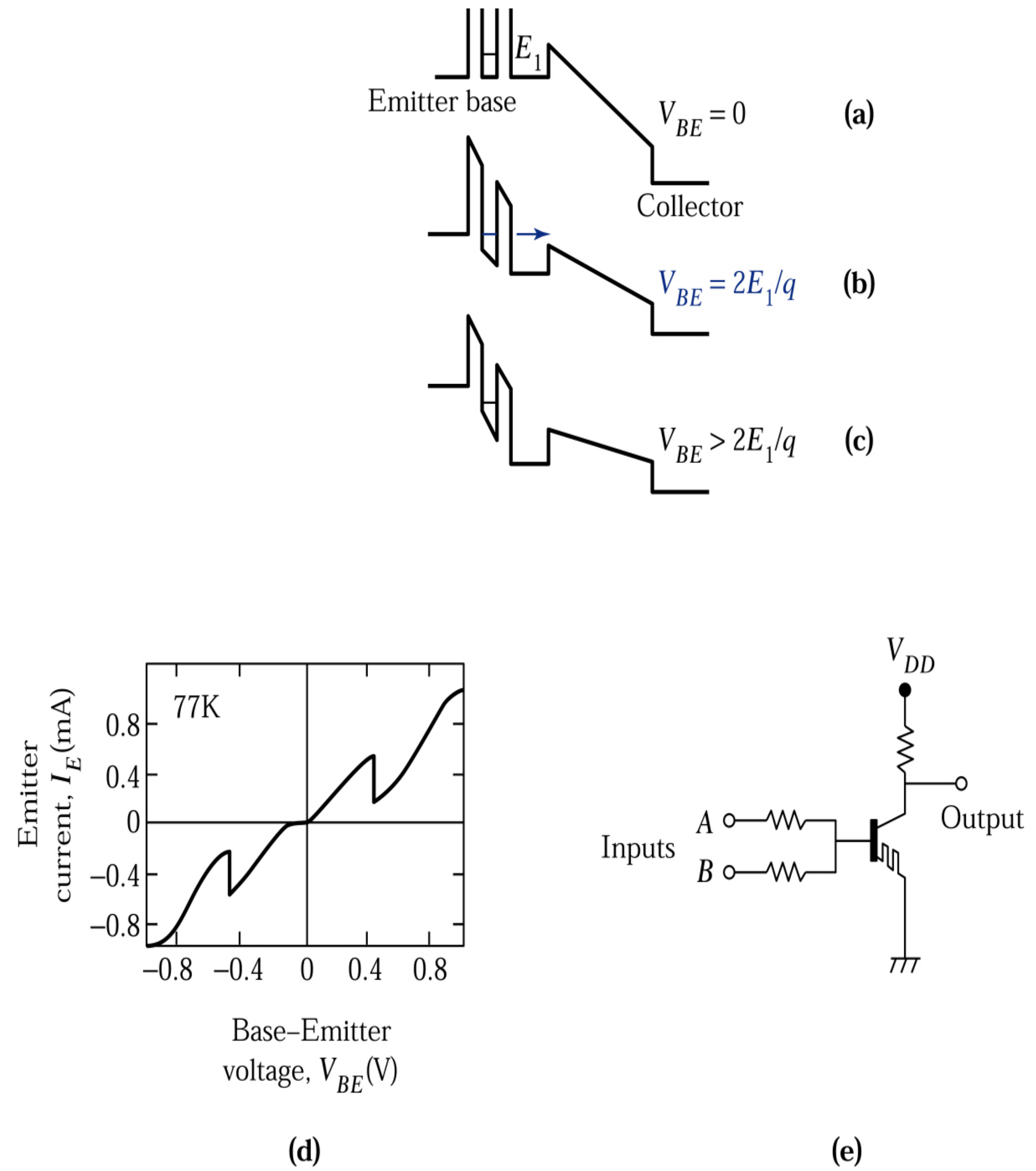
Figure 8.12.
Measured current-voltage characteristics[13] of the diode in Fig. 8-15.

注入電子能量= E1



負電阻

Figure 8.13.
Band diagrams of a unipolar resonant tunneling (RT) transistor[14] a (*a*) $V_{BE} = 0$, (*b*) $V_{BE} = 2E_1/q$ (maximum RT current), (*c*) $V_{BE} > 2E_1/q$ (RT quenched), (*d*) base-emitter current-voltage characteristics measured at 77 K, and (*e*) an exclusive NOR circuit.



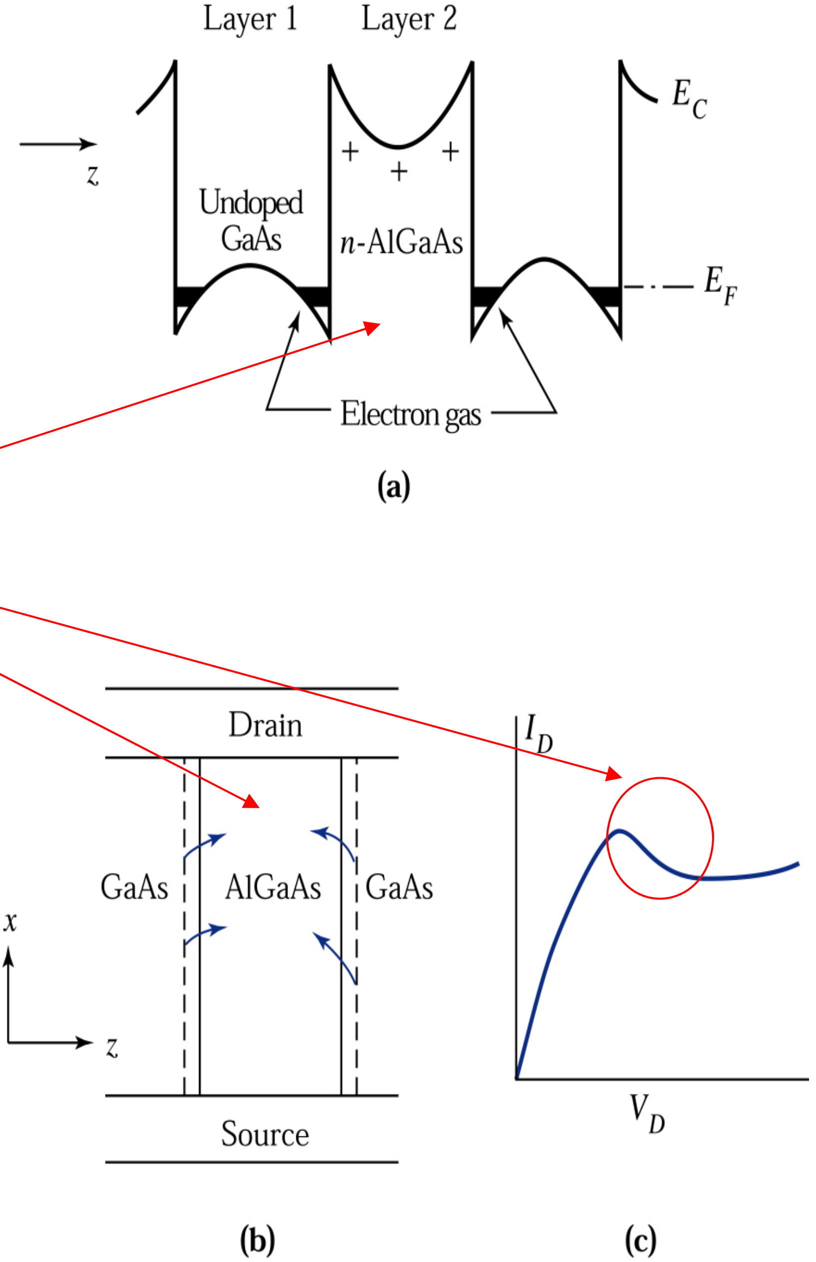
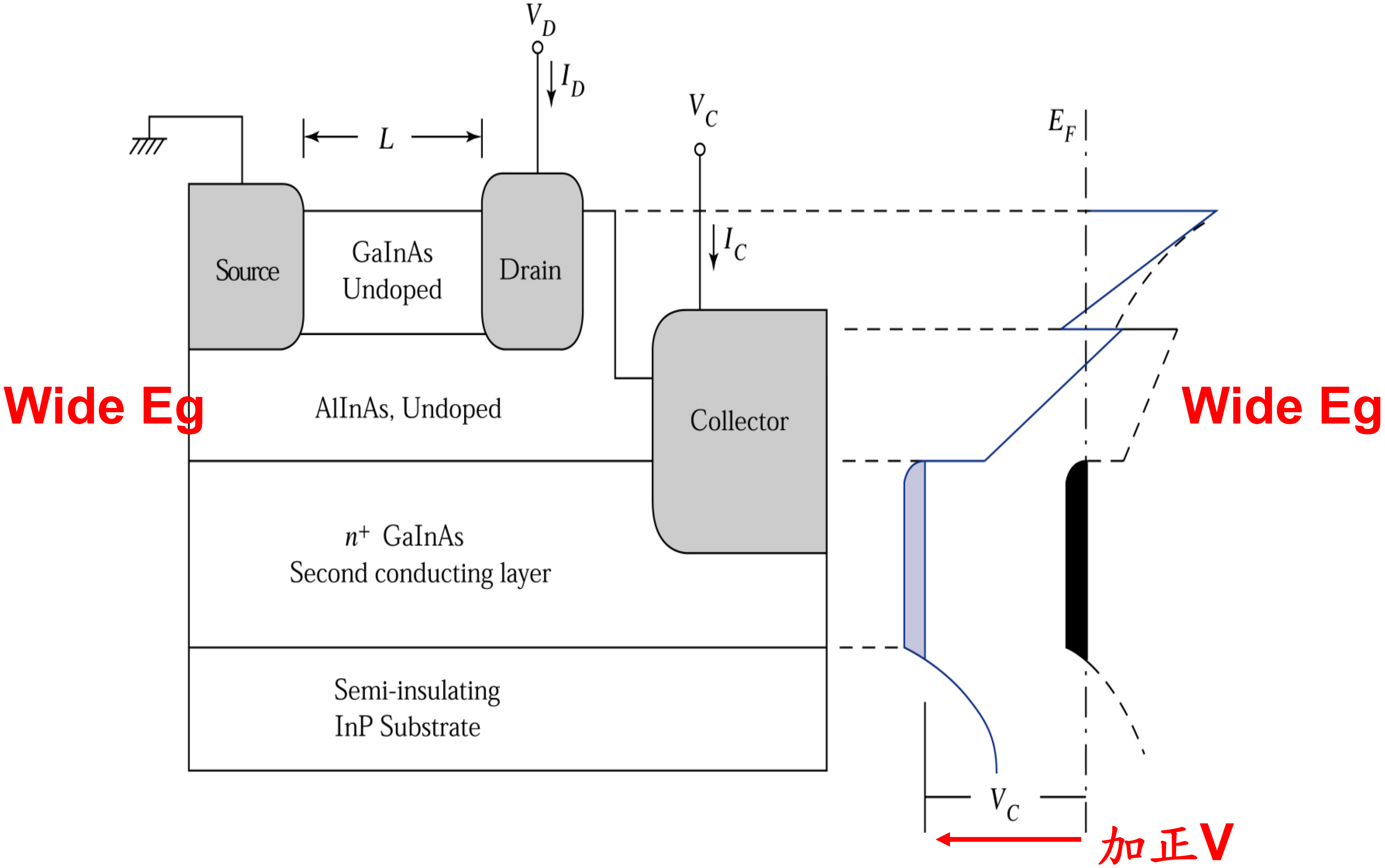


Figure 8.14.
(*a*) A heterostructure with alternate GaAs and AlGaAs layers. (*b*) Electrons, heated by an applied electric field, transfer into the wide-gap layers. (*c*) If **the mobility in layer 2 is lower**, the transfer results in a negative differential conductivity.



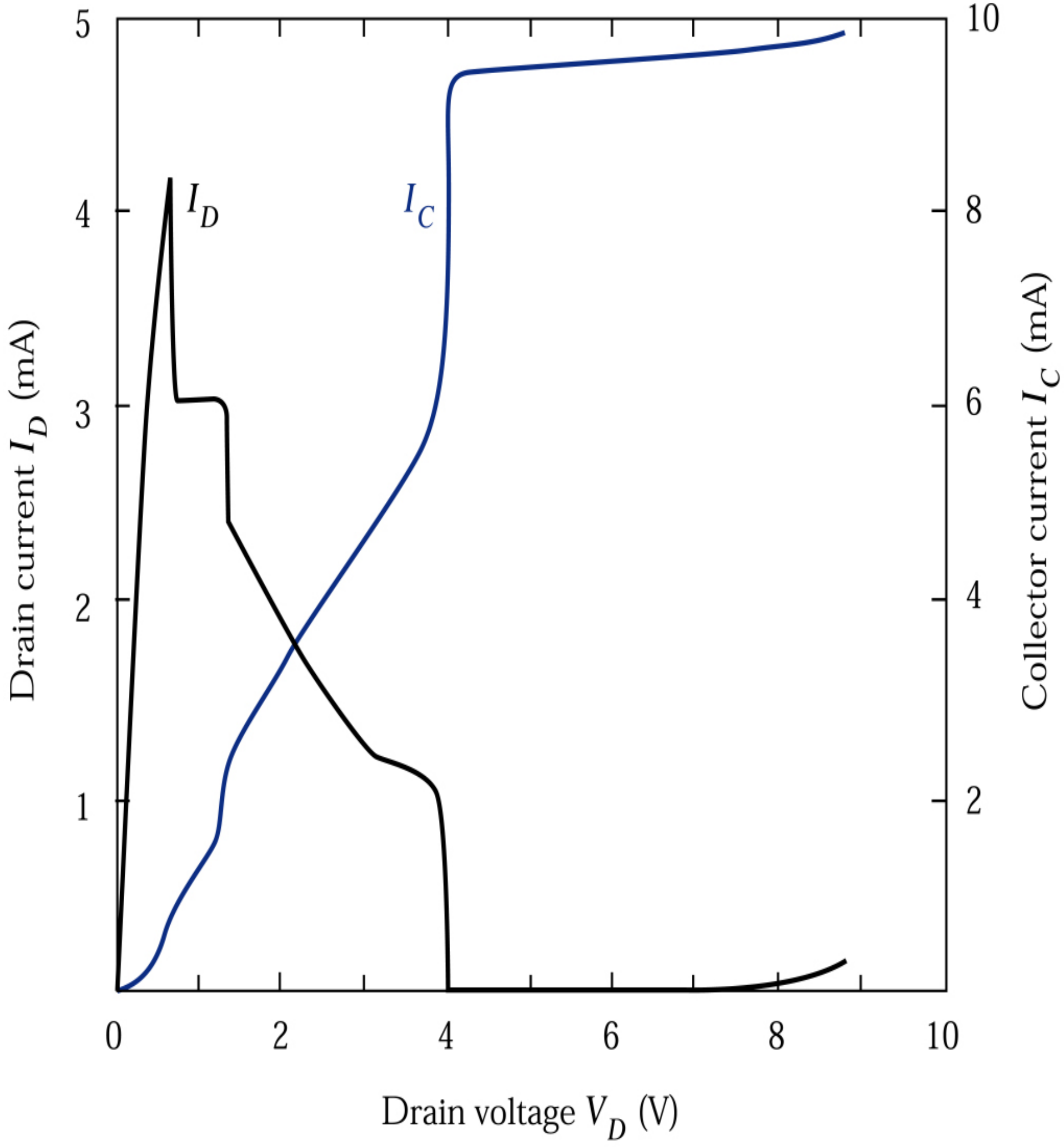
Wide Eg

Wide Eg

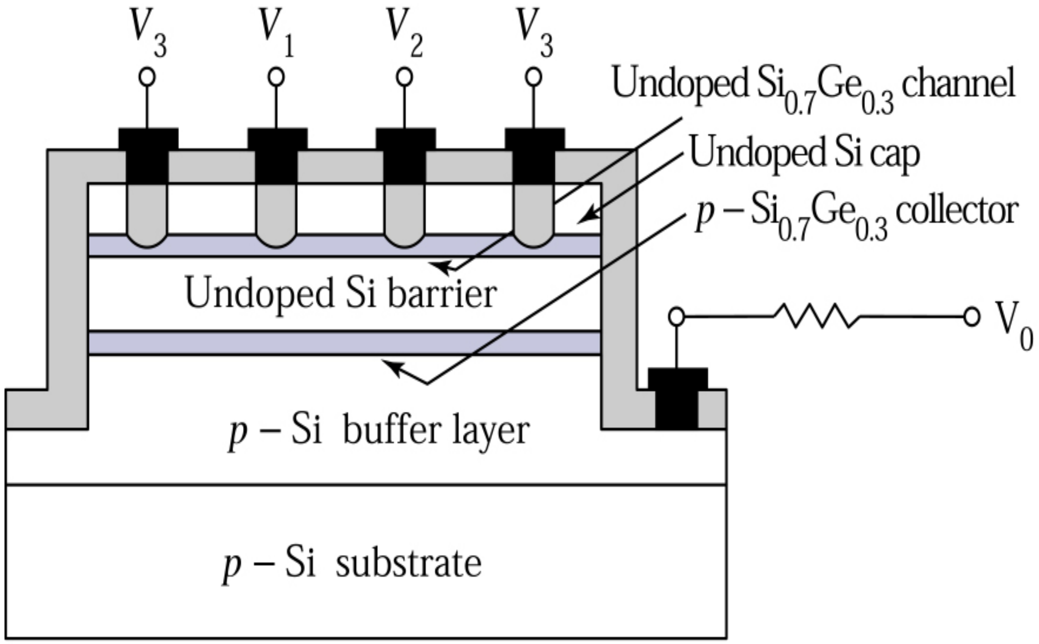
加正V

Figure 8.15. Cross section and band diagram of a real-space-transfer transistor in a GaInAs/AlInAs material system.

Figure 8.16. Experimental real-space-transfer transistor characteristics[19] at T = 300 K. Drain current I_D and collector current I_C versus drain voltage V_D at a fixed collector voltage V_C = 3.9 V.



Ic ↑,
I_D 流過wide Eg,
μ↓, I_D ↓



(a)

V_1	V_2	V_3	V_0	Logic
0	0	0	0	OR
1	0	0	1	
0	1	0	1	
1	1	0	1	
0	0	1	1	NAND
1	0	1	1	
0	1	1	1	
1	1	1	0	

(b)

(*a*) A Si/SiGe RSTT OR-NAND gate with three inputs. The channel length between different inputs is 1 μm, and the device width is 50 μm. (*b*) Truth table for OR-NAND logic operation.[20]