# Semiconductor Devices

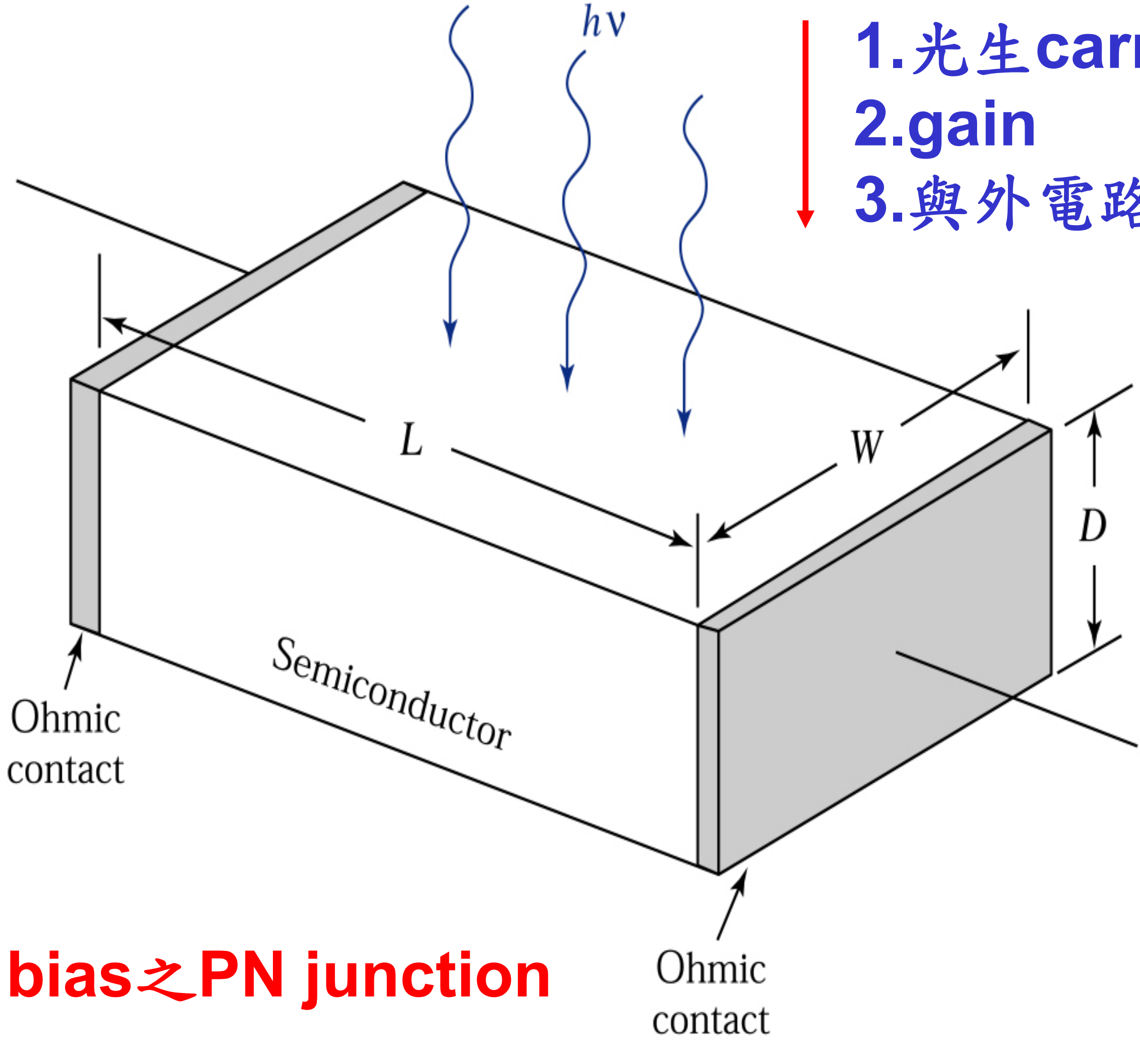
**THIRD EDITION**

**S. M. Sze and M. K. Lee**

## Chapter 10

Photodetectors and Solar Cells

1.光生carrier
2.gain
3.與外電路作用




操作在反向bias之PN junction

**Figure 10.1a.** Schematic diagram of a photoconductor that consists of a slab of semiconductor and two contacts at the ends.

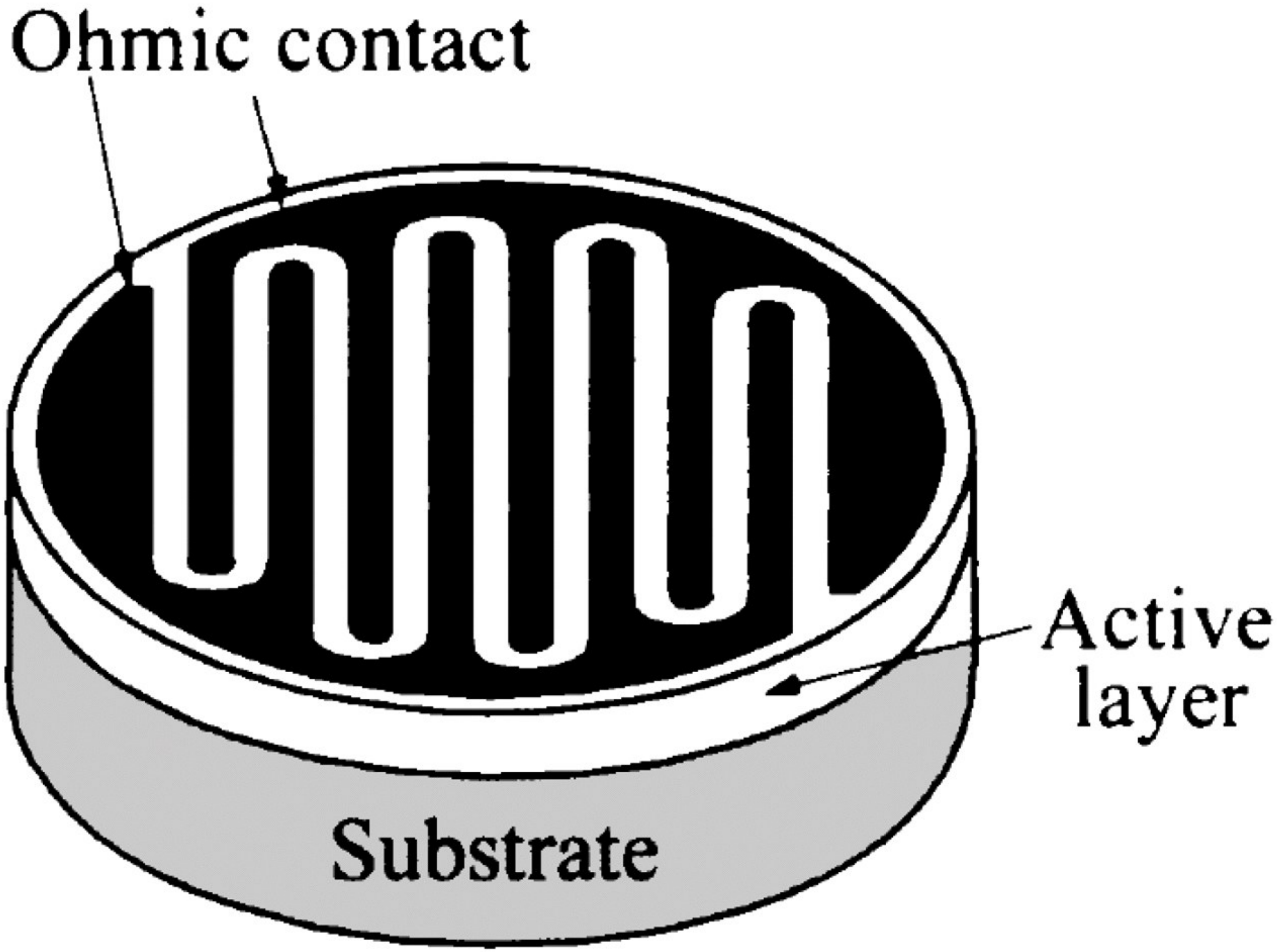
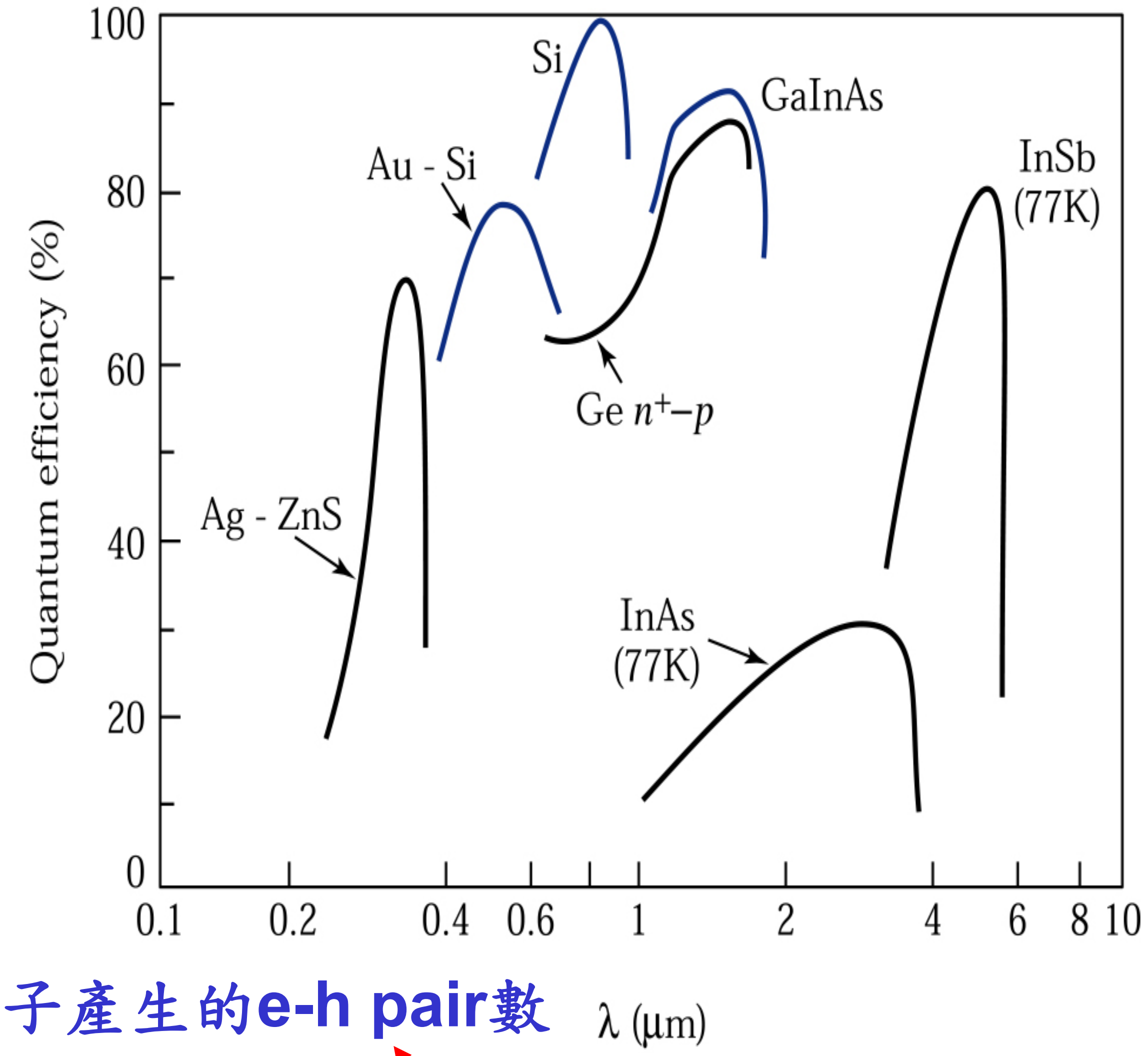



Figure 10.1b


Layout: interdigit with a small gap




每個光子產生的e-h pair數

**Figure 10.2.** Quantum efficiency versus wavelength for various photodetectors.[21,22]

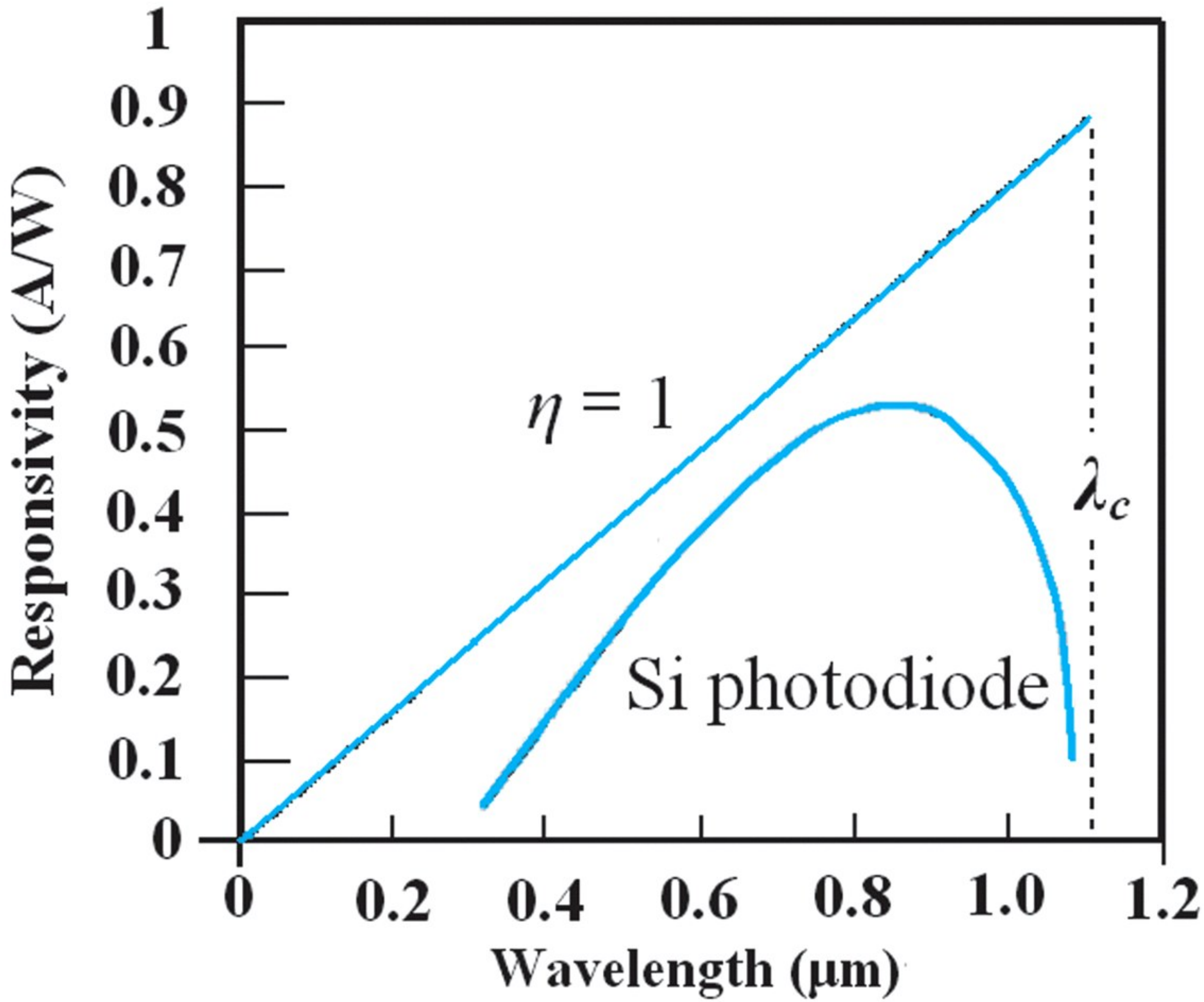


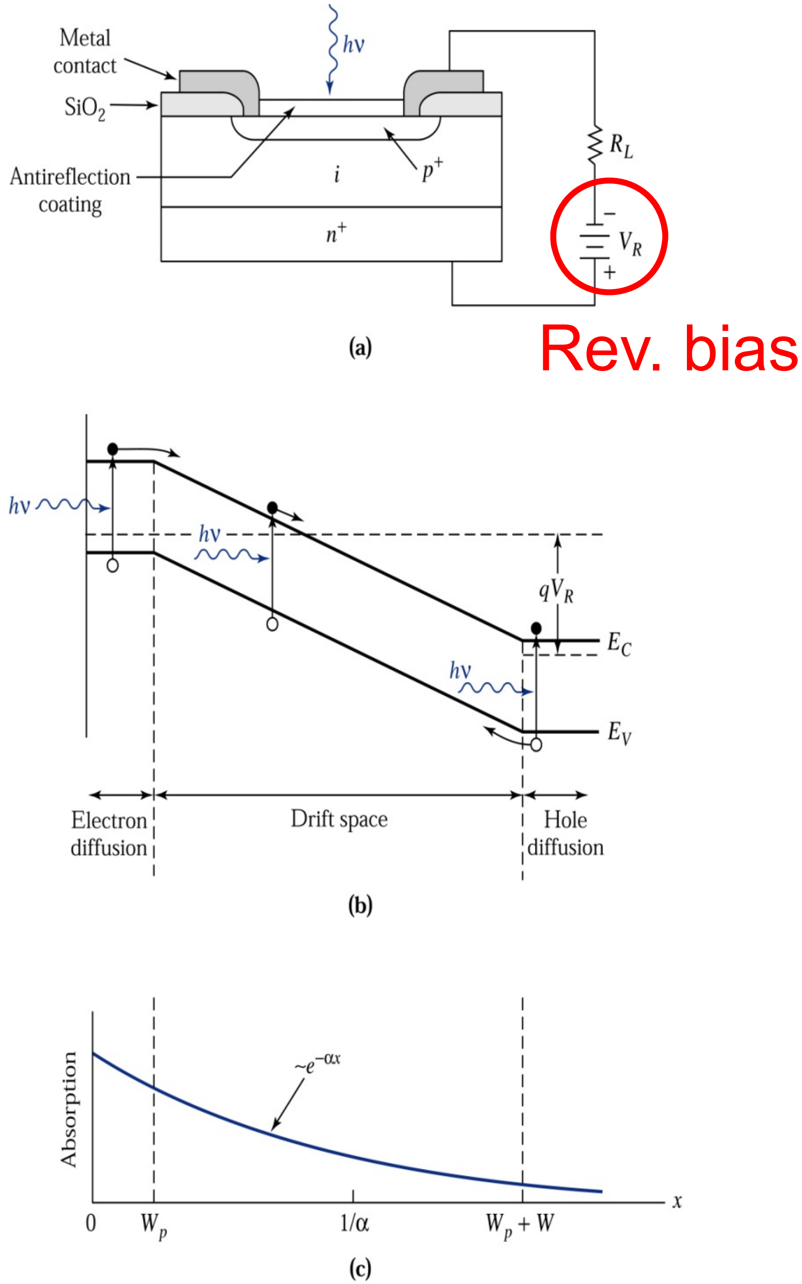

Figure 10.3



Ideal and typical commercial one

**Figure 10.4.**
Operation of a *p-i-n* photodiode. (*a*) Cross-section view of a *p-i-n* photodiode. (*b*) Energy band diagram under reverse bias. (*c*) Carrier absorption characteristics.

最常用



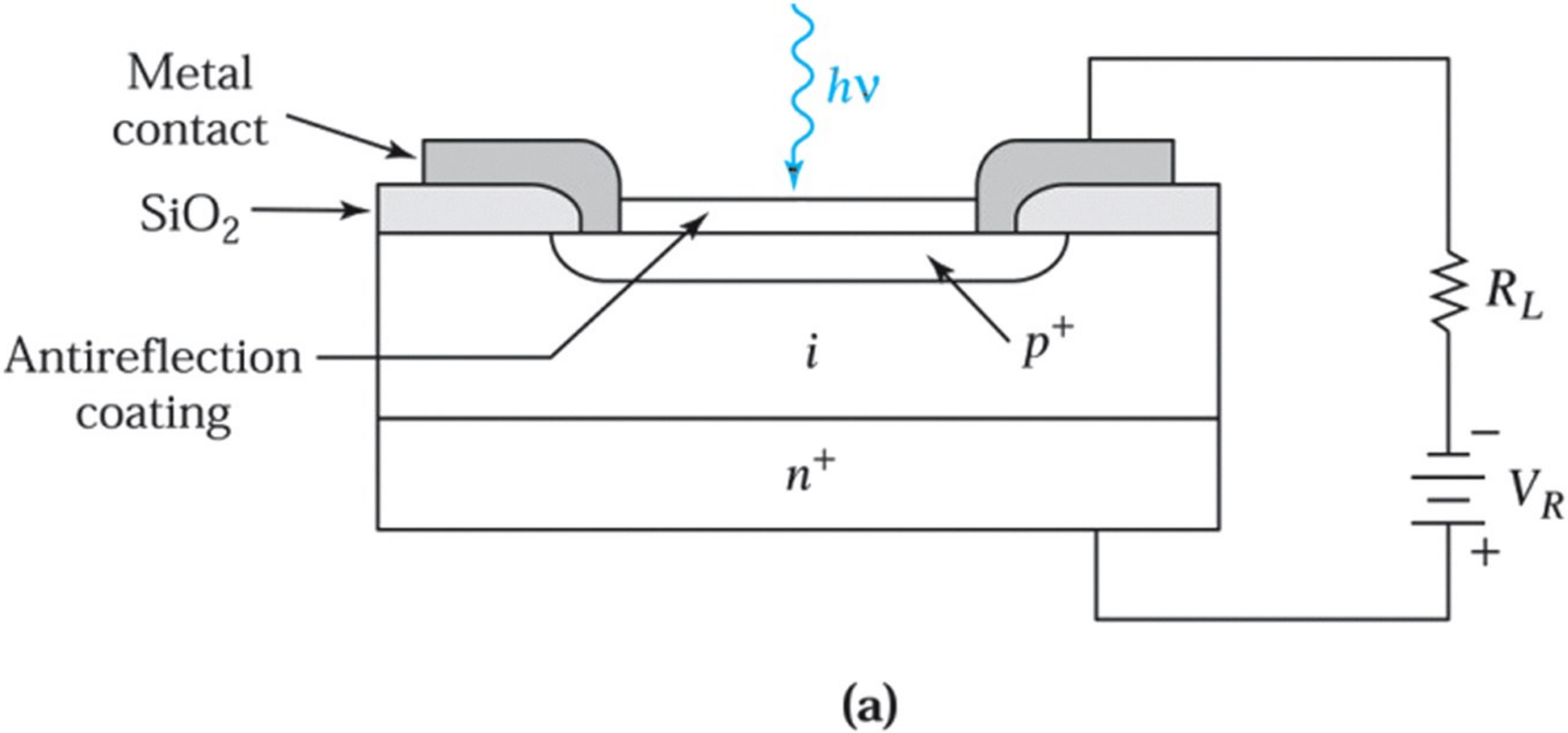



Figure 10.4a

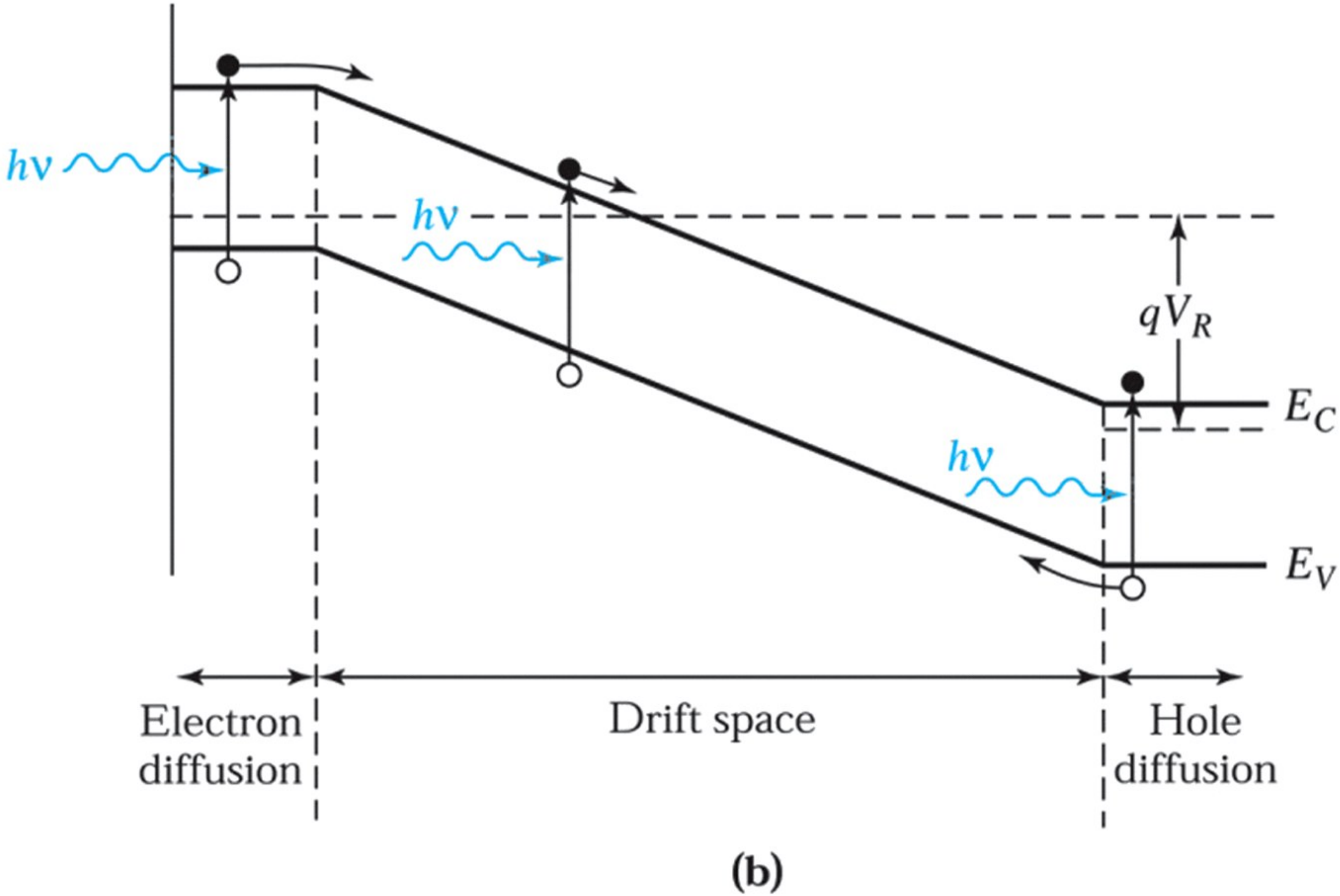

hν
hν
hν
qV_R
E_C
E_V
Electron diffusion
Drift space
Hole diffusion
(b)

Figure 10.4b

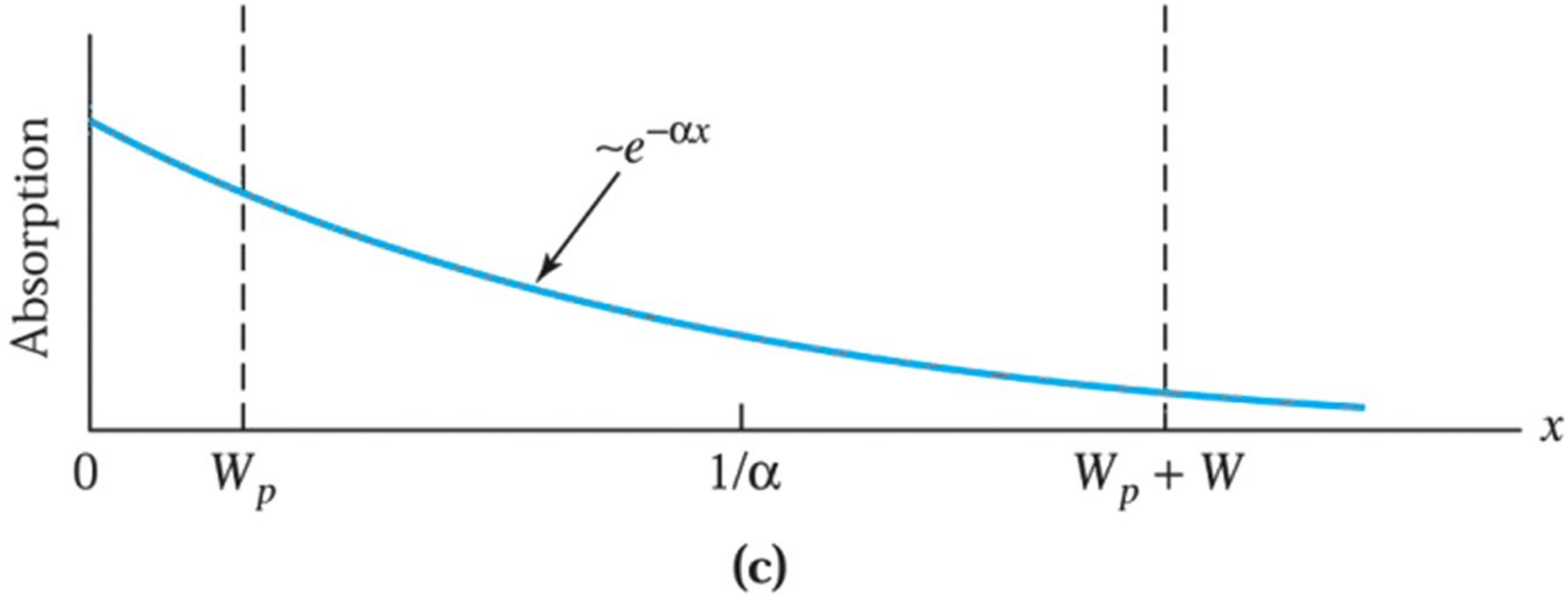
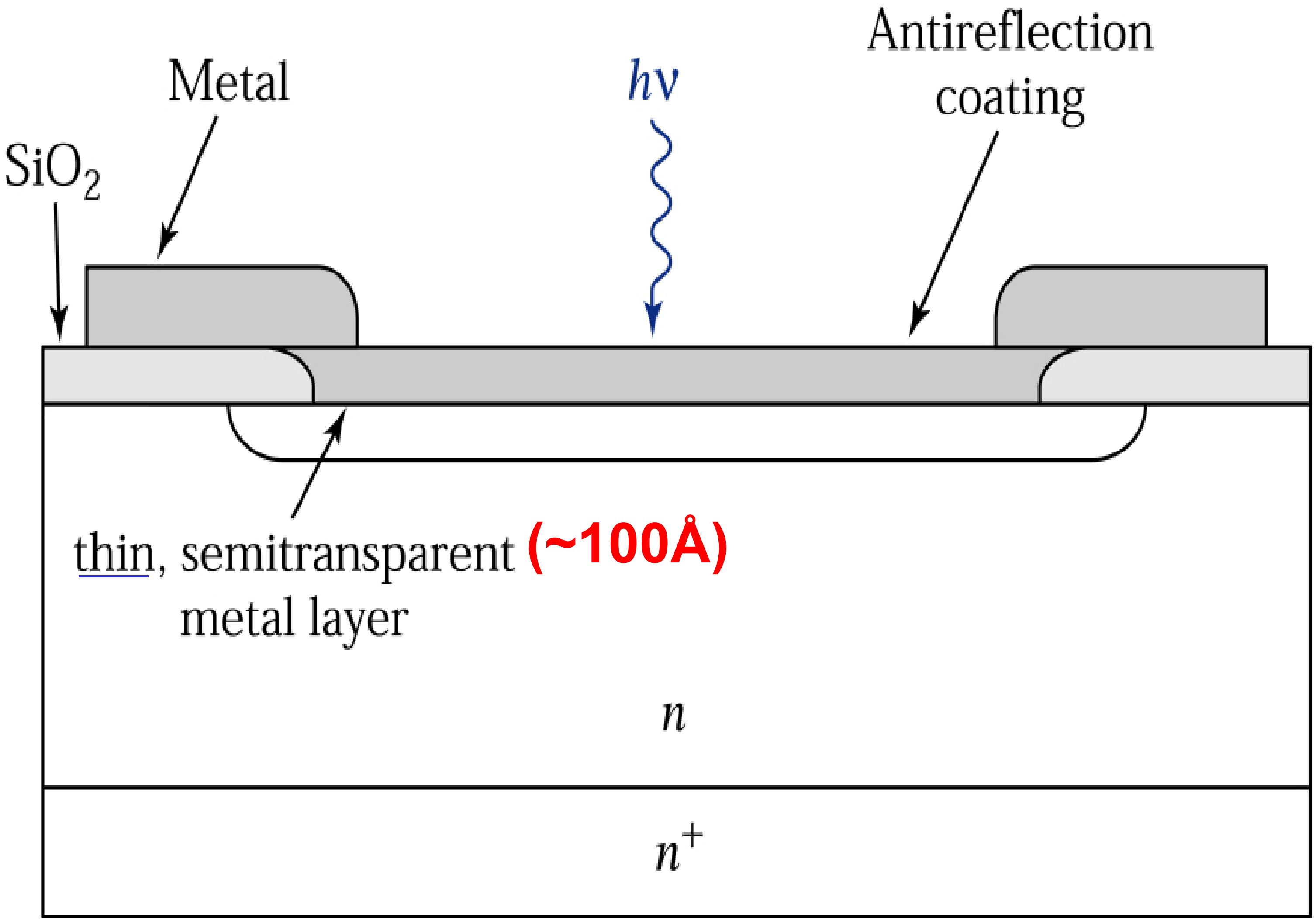
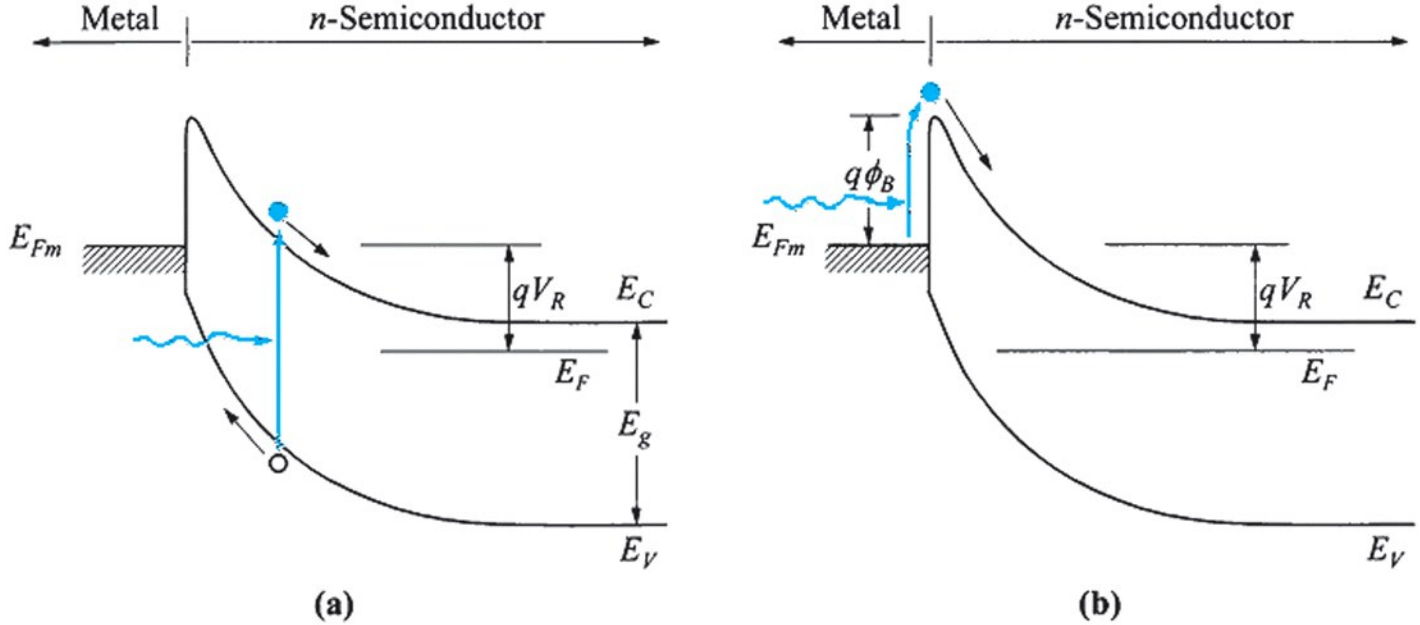



Figure 10.4c




*沒有P+之吸收

**Figure 10.5.** Metal-semiconductor photodiode.




**(a) hv> Eg**
**(b) $q\Phi_B$< hv <Eg**
**(c) Both processes**

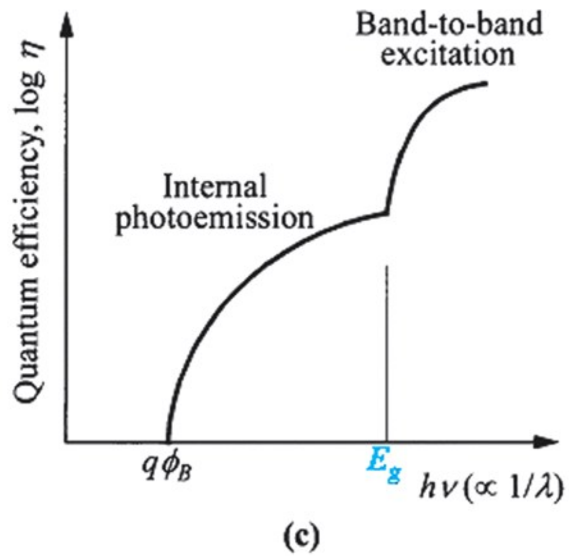



Figure 10.6

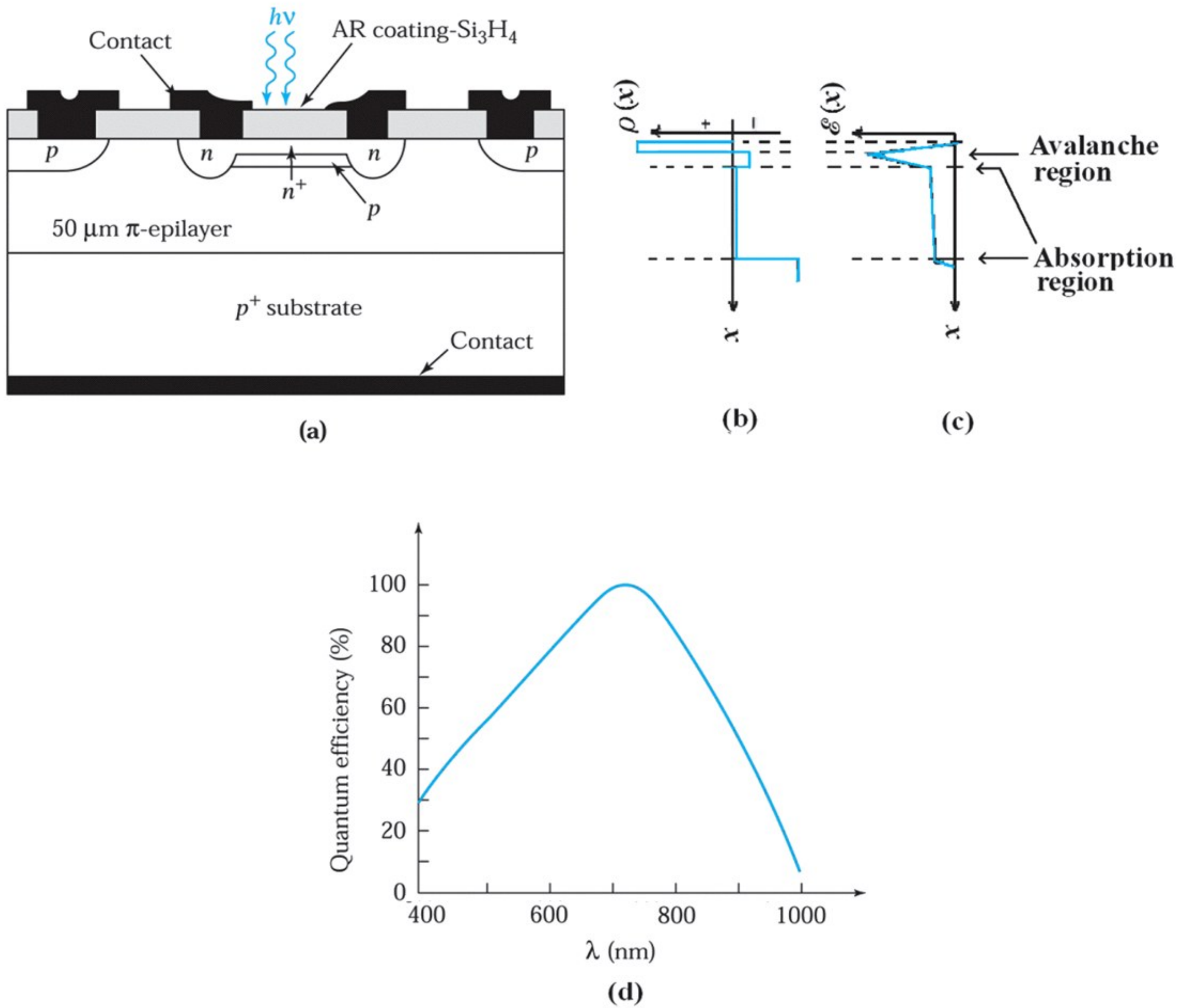



**Figure 10.7.**
A typical silicon **avalanche photodiode:** (*a*) device structure and (b)space charge (c) electric field (*d*) quantum efficiency.

**Avalanche: carrier 放大,**
**要避免leakage, breakdown**

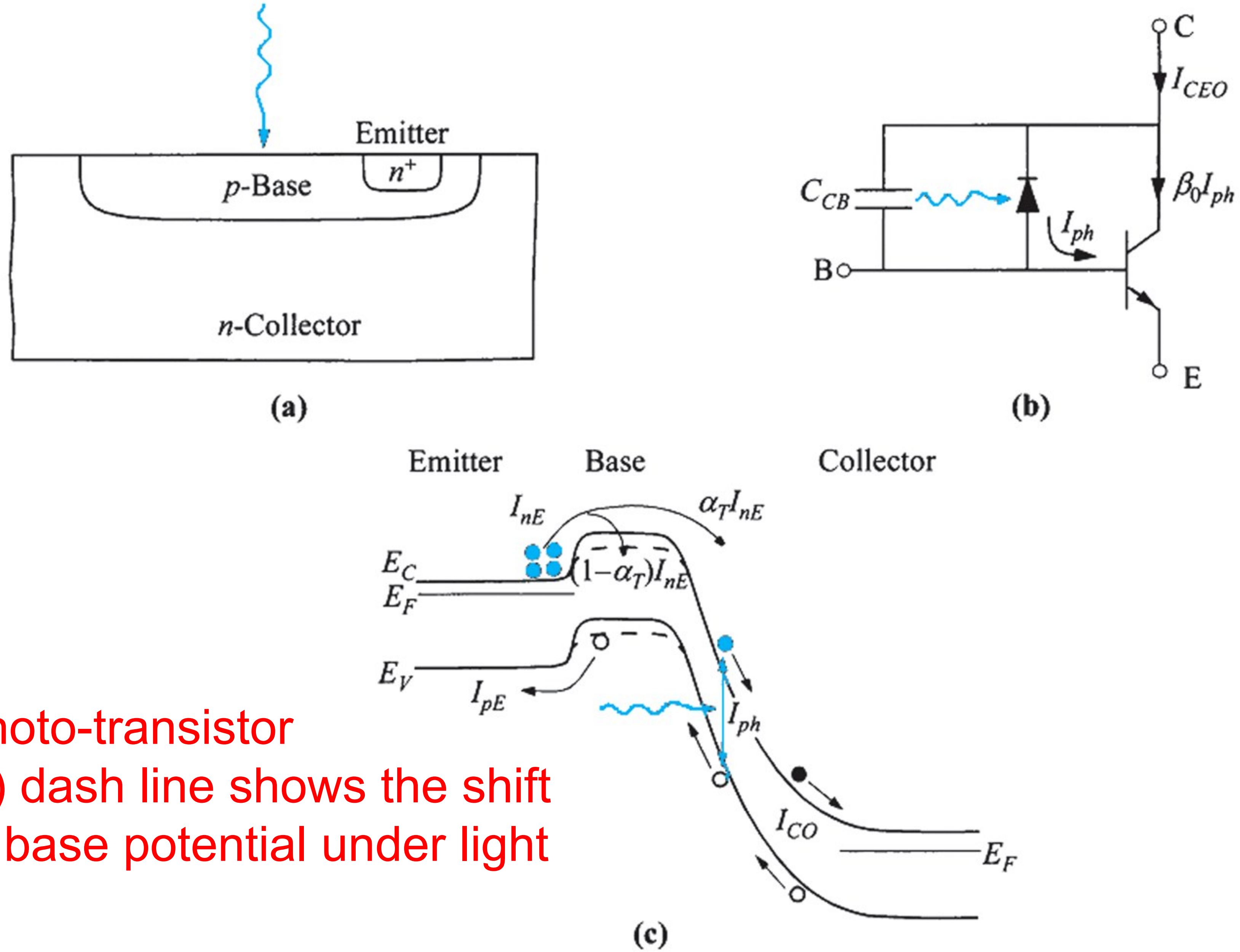



Photo-transistor

(c) dash line shows the shift of base potential under light

Figure 10.8

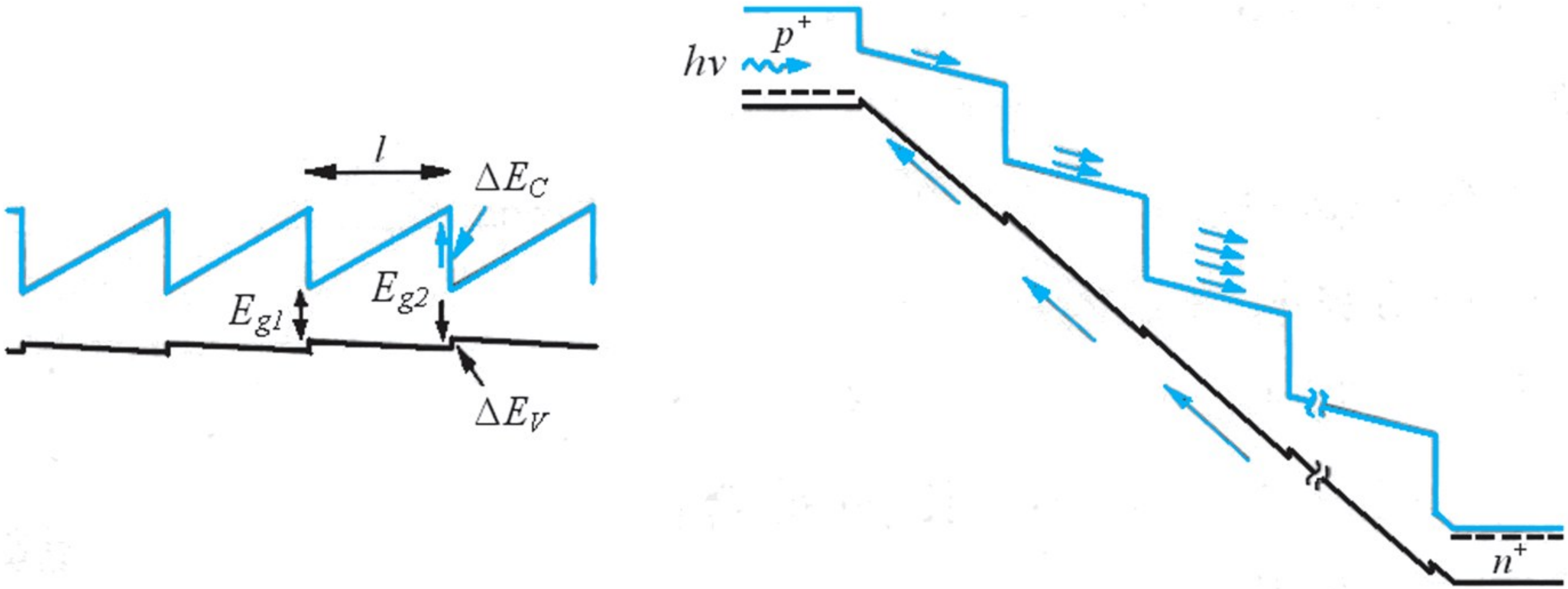



**Figure 10.9**
Reprinted with permission from *Applied Physics Letters*, 40 (38), F. Capasso et. al, "Enchantment of Electron Impact Ionisation in a Superlattice: A New Avalanch Photodiode with a Large Ionisation Rate Ratio", Copyright 1982 American Institute of Physics.

A staircase superlattice APD
No high E, low noise

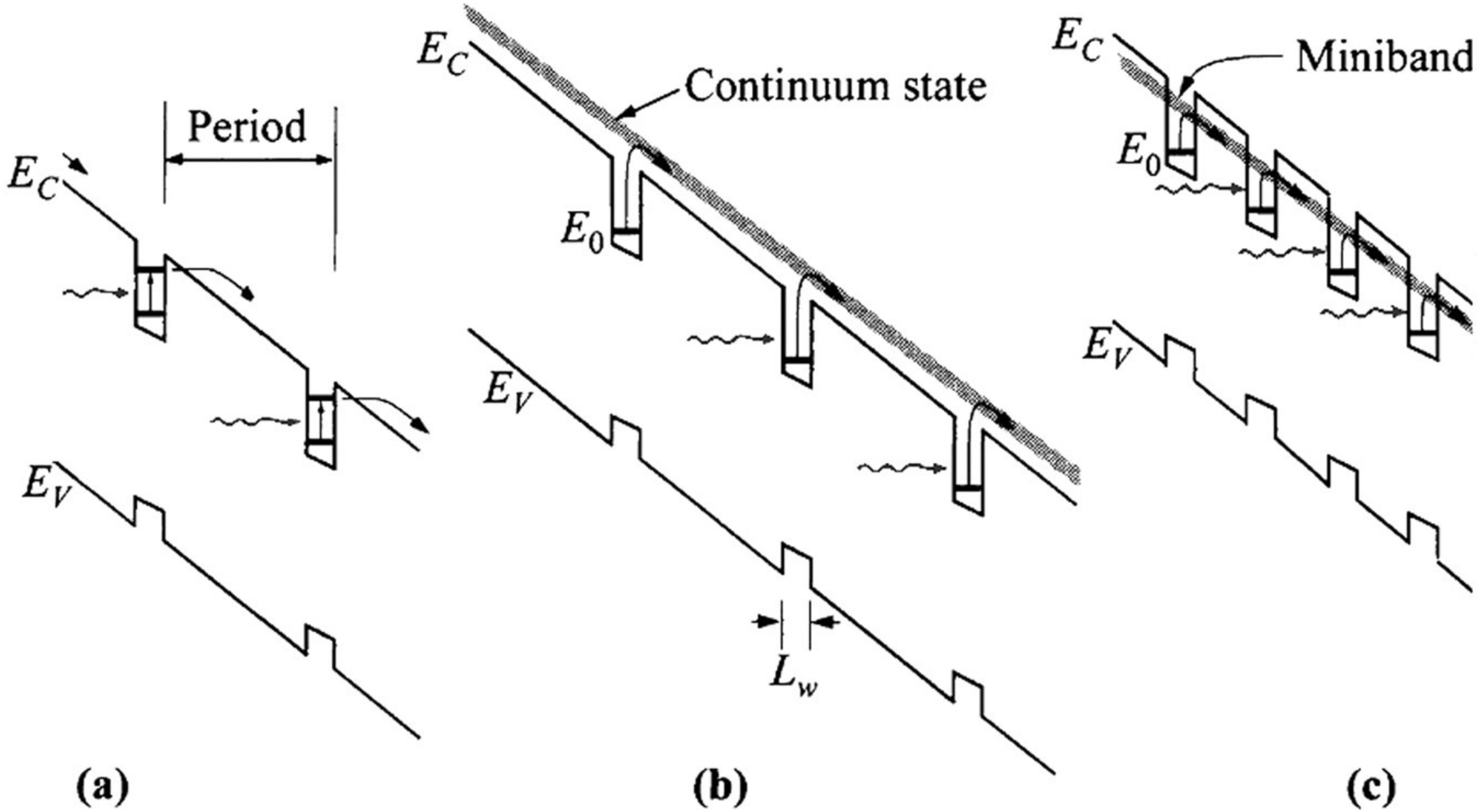



Figure 10.10


A quantum-well infrared photodetector (QWIP)

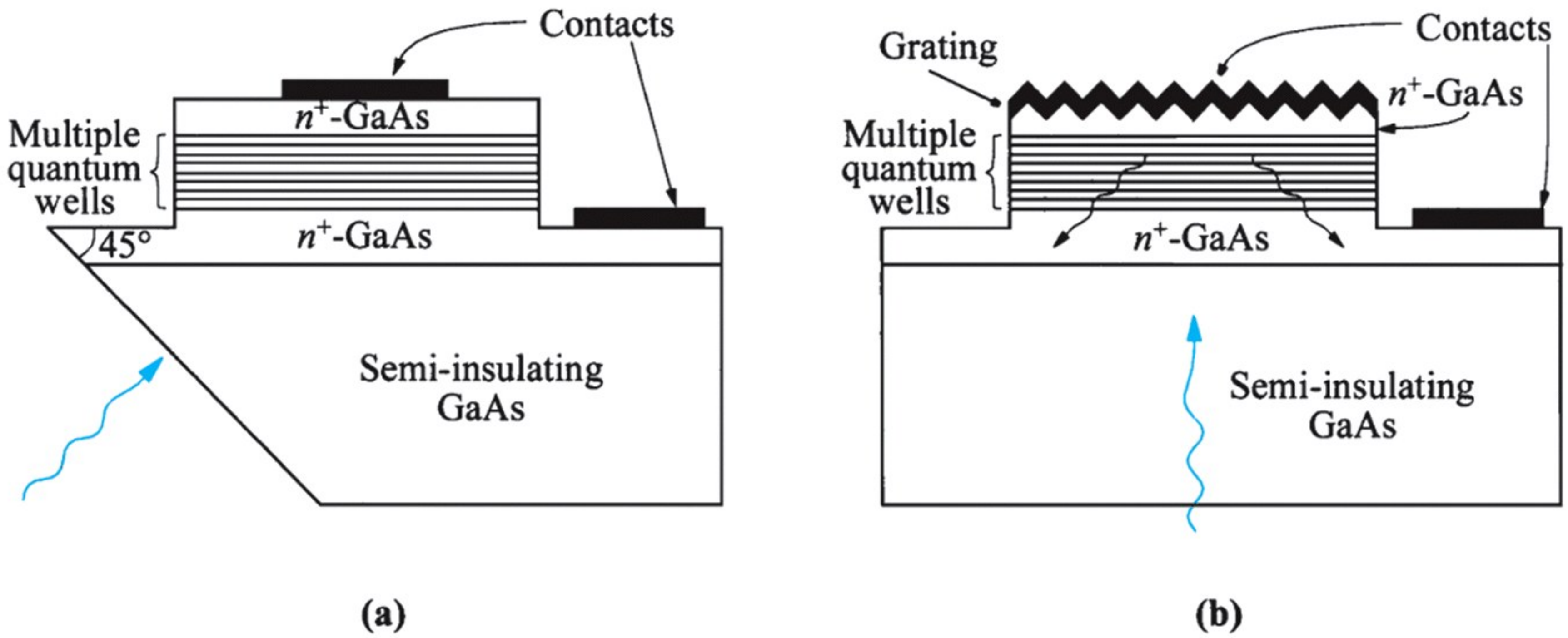
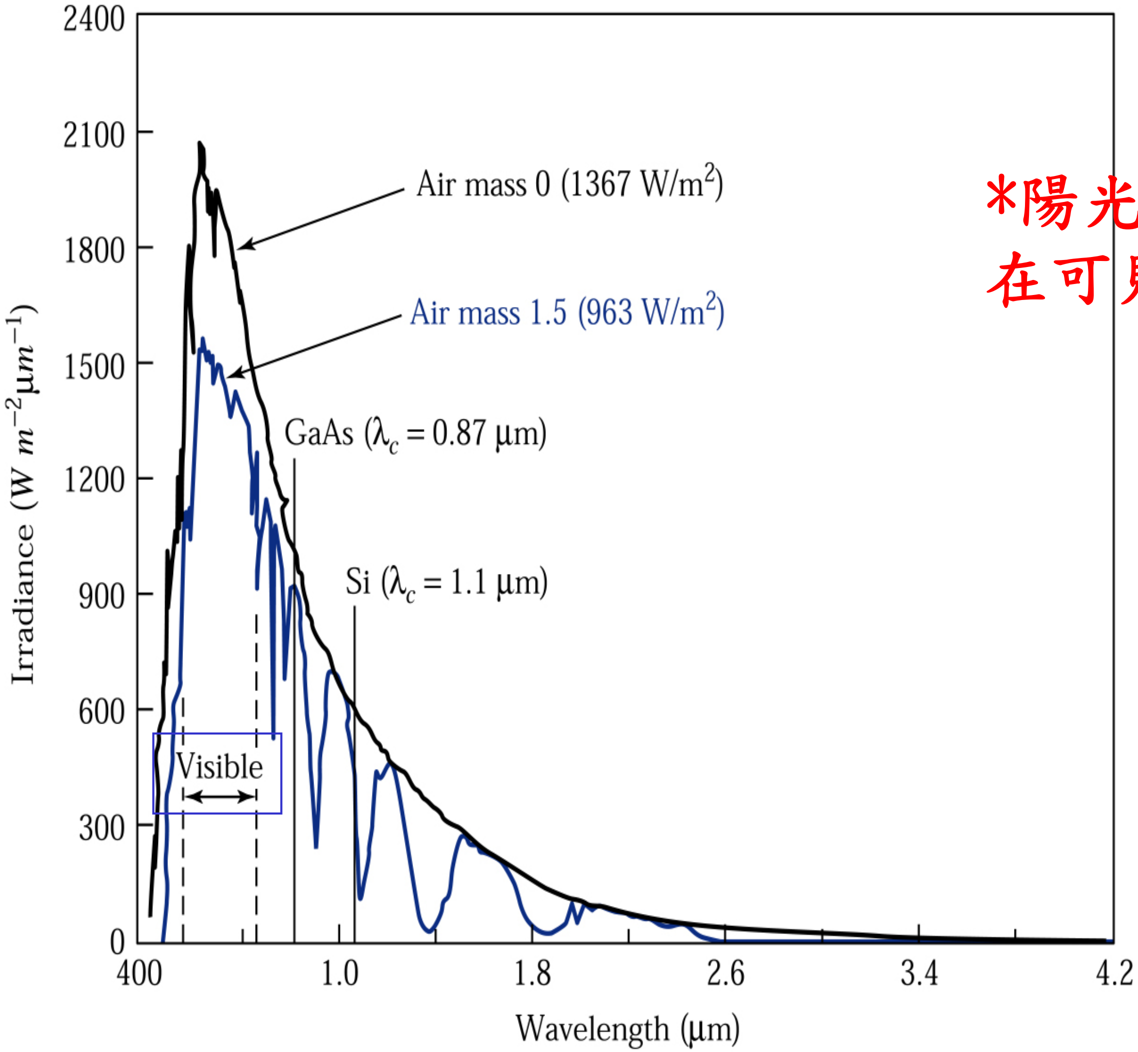



Figure 10.11

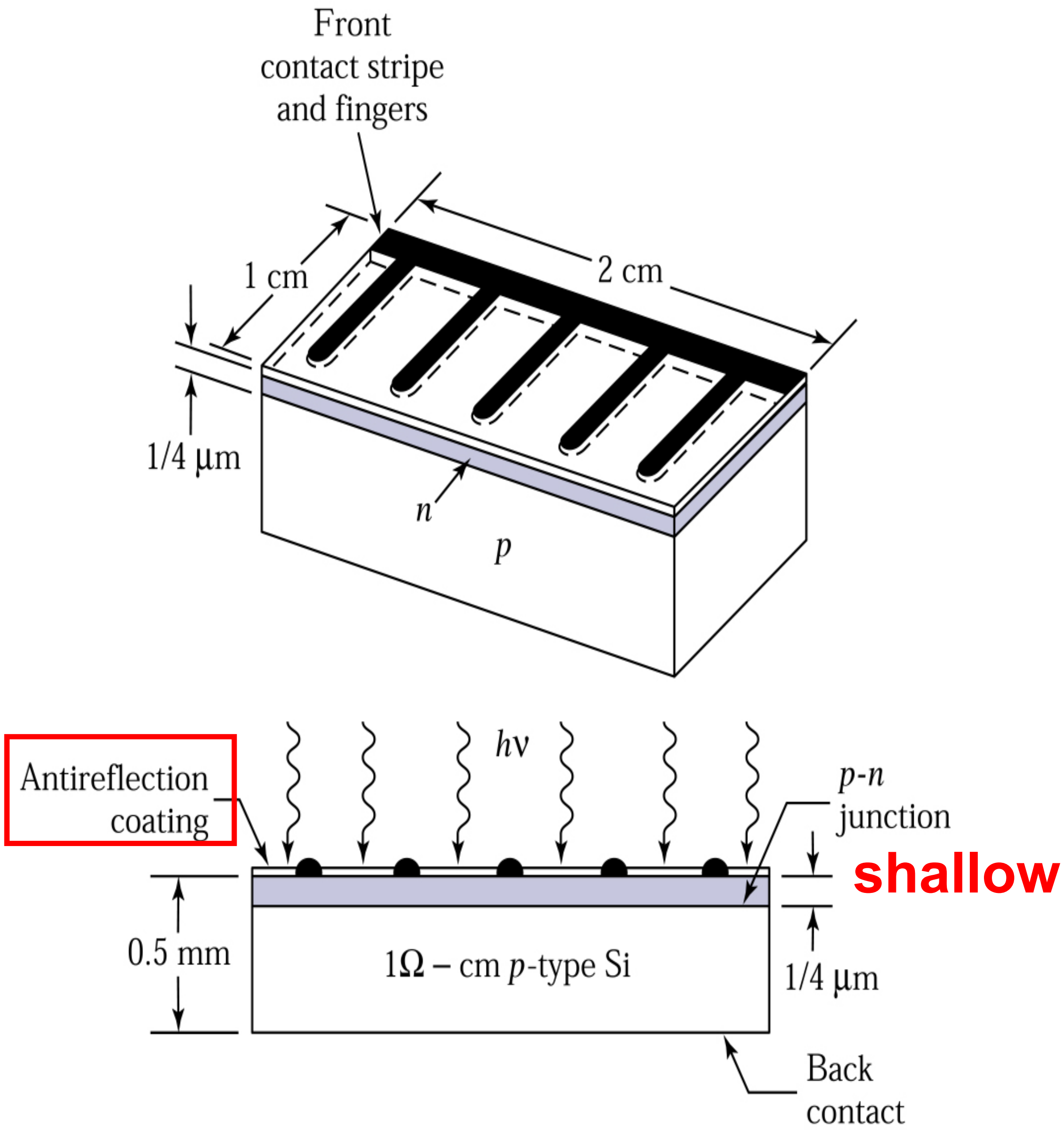

(a) Light normal to 45° face, transparent to substrate
(b) Grating on the top

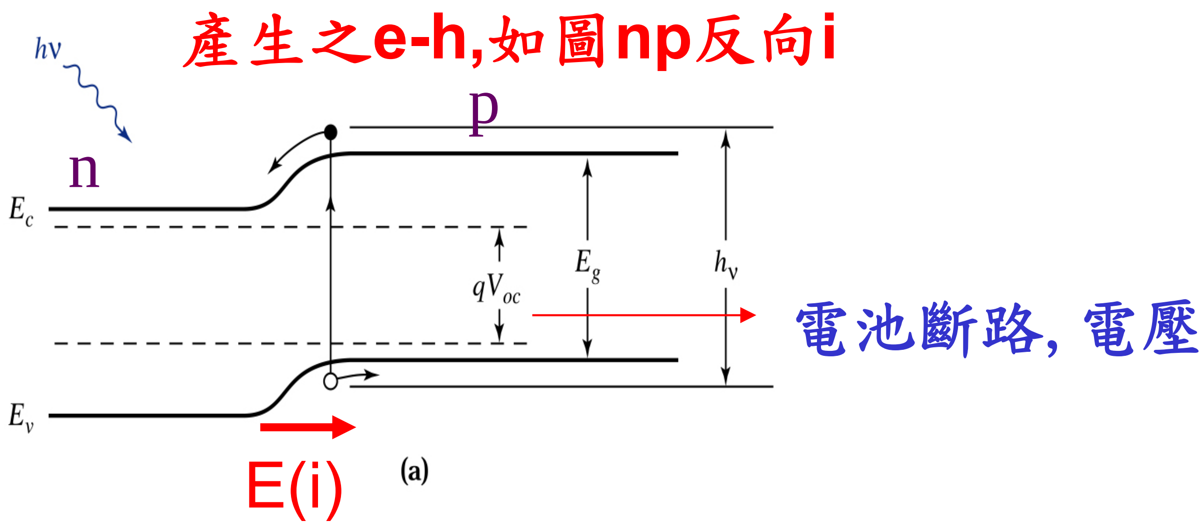



*陽光中主要能量在可見光

**Figure 10.12.** Solar spectral irradiance[25] at air mass 0 and air mass 1.5 and the cutoff wavelength of GaAs and Si.

**Figure 10.13.** Schematic representation of a silicon *p-n* junction solar cell.[23]





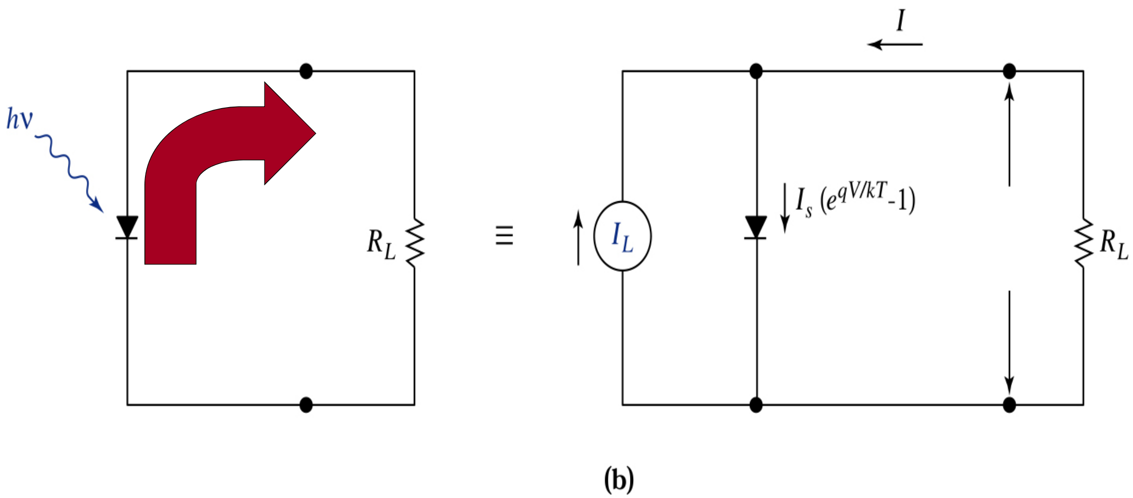




**Figure 10.14.** (*a*) Energy band diagram of a *p-n* junction solar cell under solar irradiation. (*b*) Idealized equivalent circuit of a solar cell.

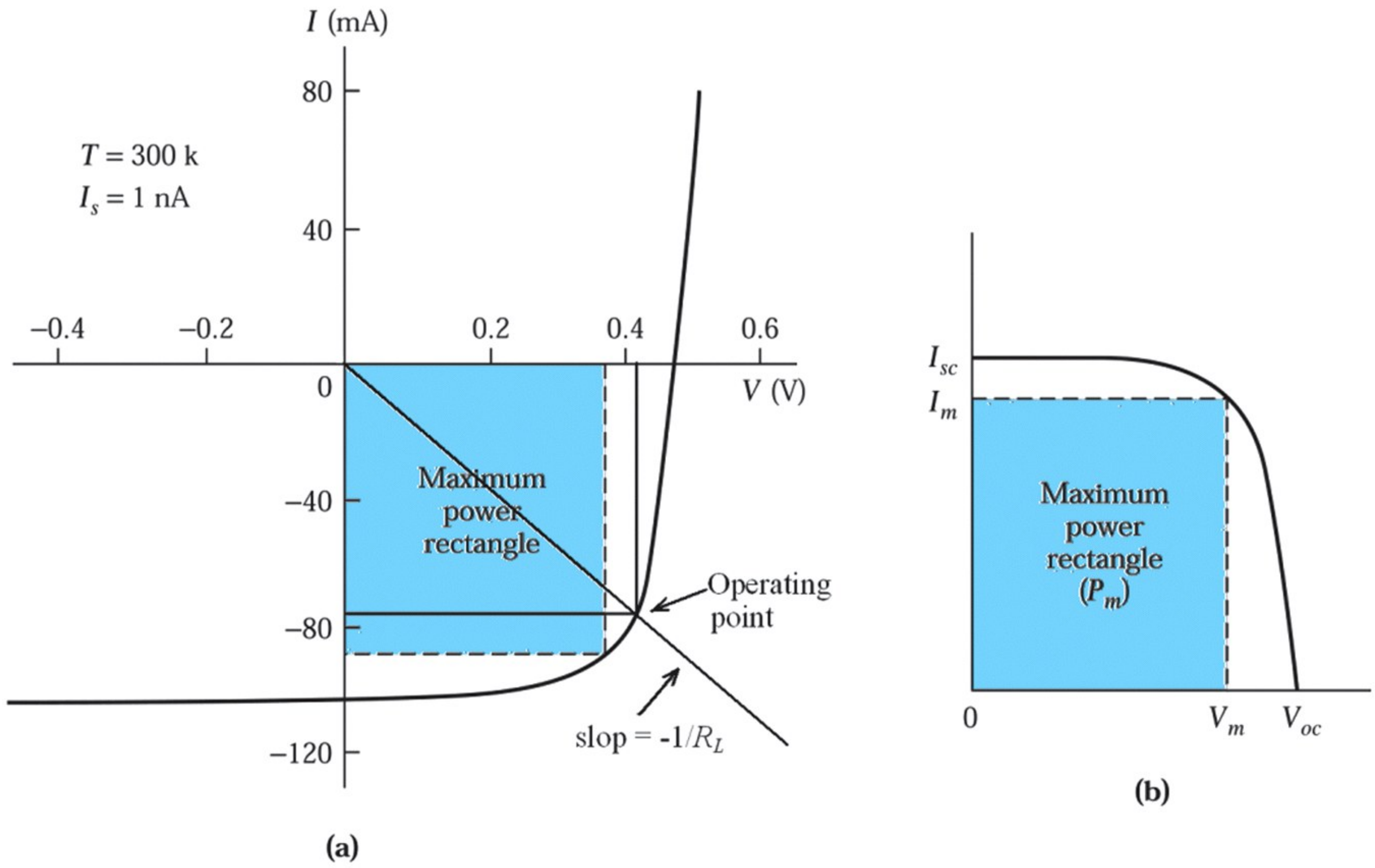
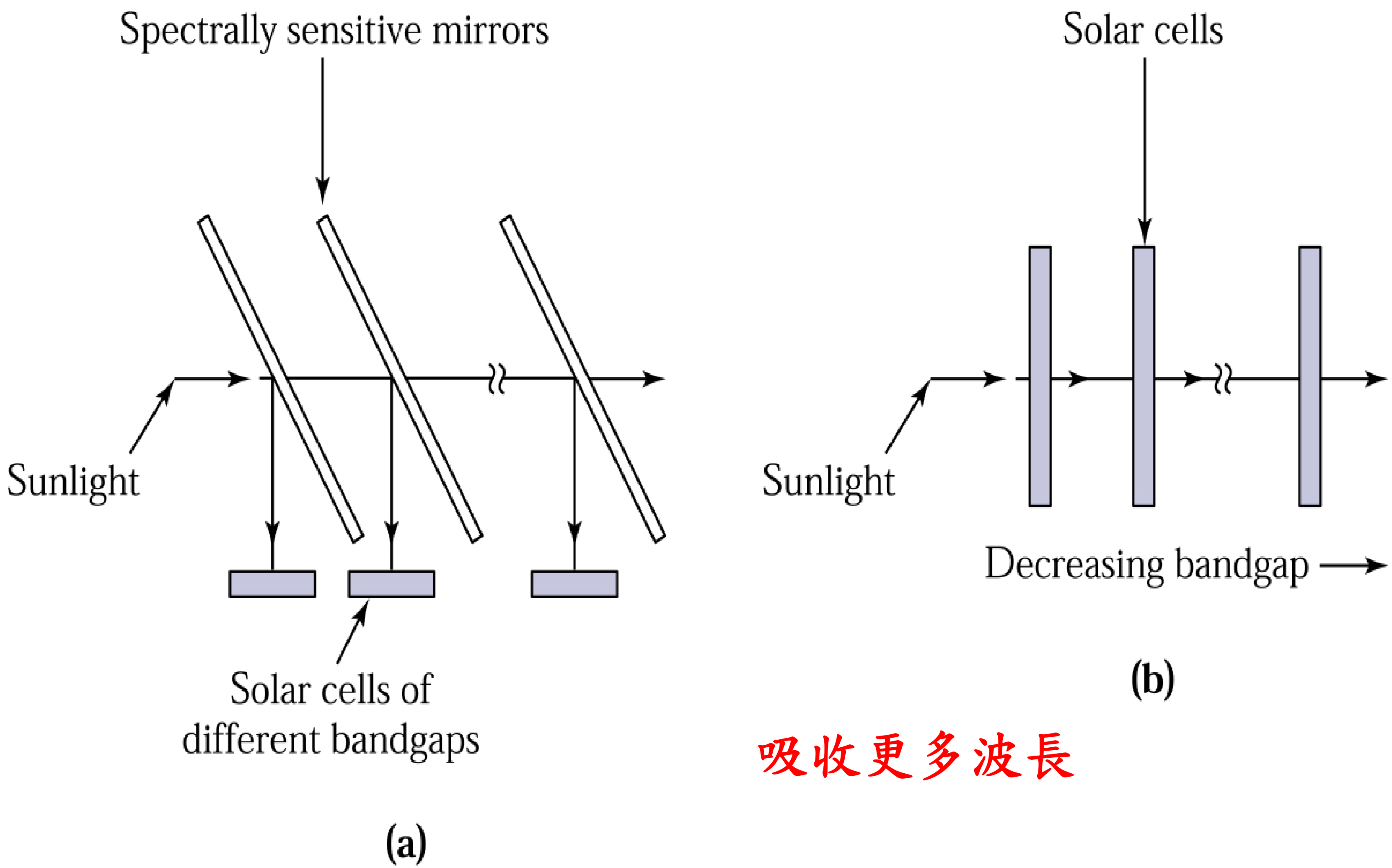



Figure 10.15

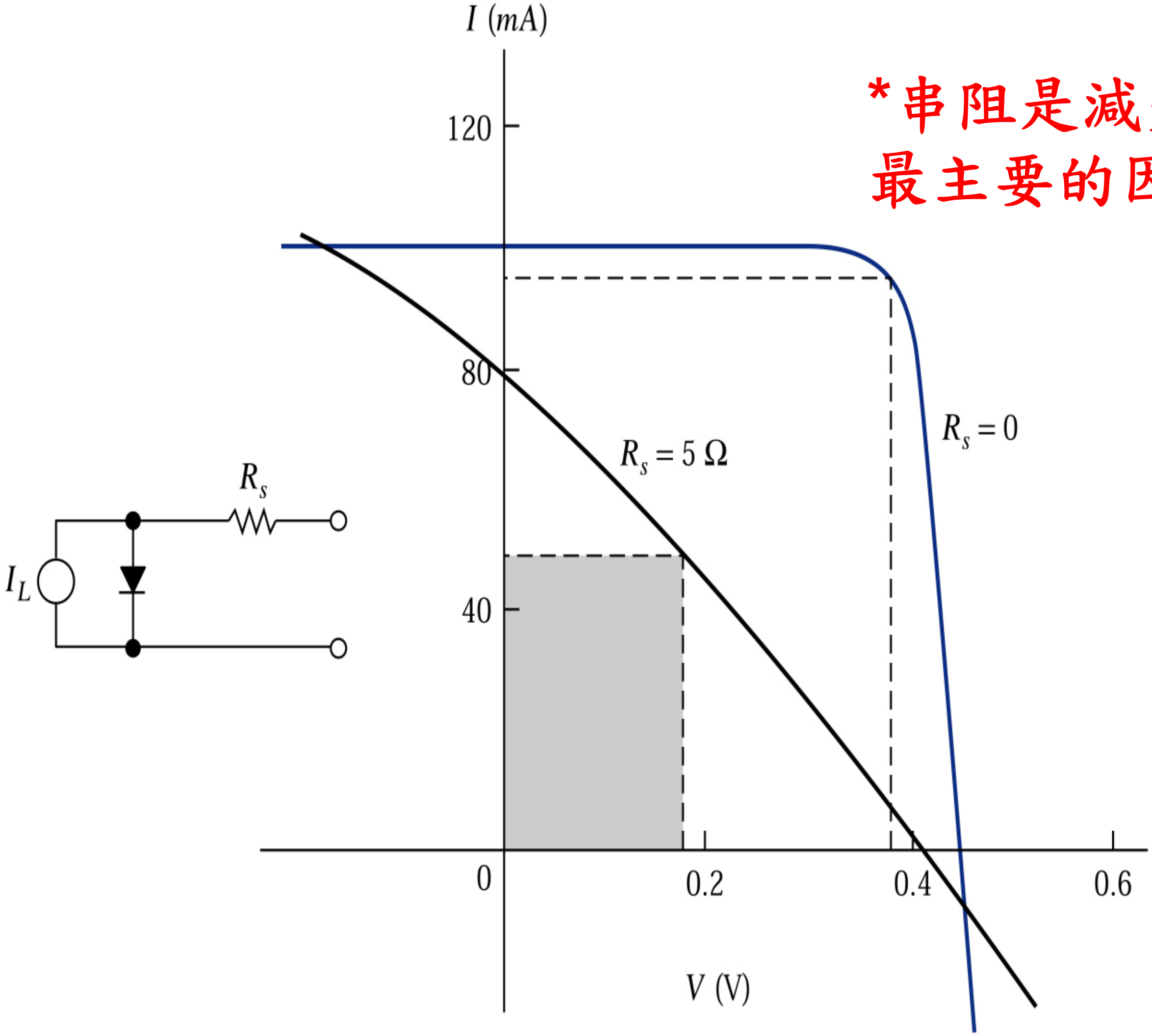


**Figure 10.15.** (*a*) Current voltage characteristics of a solar cell under illumination. (*b*) Inversion of (*a*) about the voltage axis.




吸收更多波長

**Figure 10.16.** Multigap cell concepts. (*a*) Spectrum splitting approach. (*b*) Tandem-cell approach.[27]




*串阻是減少eff.
最主要的因素

**Figure 10.17.** Current-voltage characteristics and the equivalent circuit of solar cells that have resistances.

**Reduce reflection**

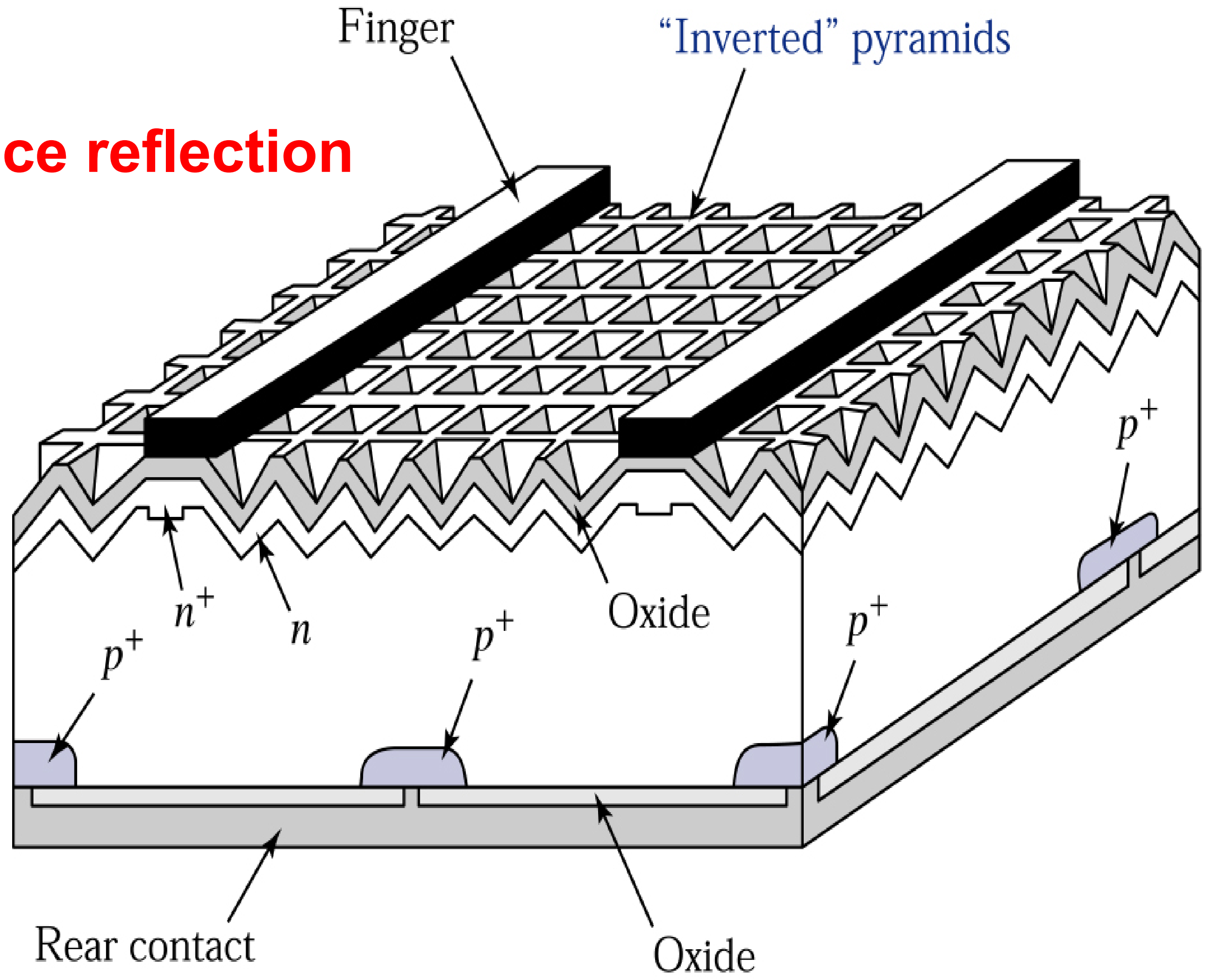



**Figure 10.18a.** Passivated emitter near locally diffused (PERL) cell.[24]

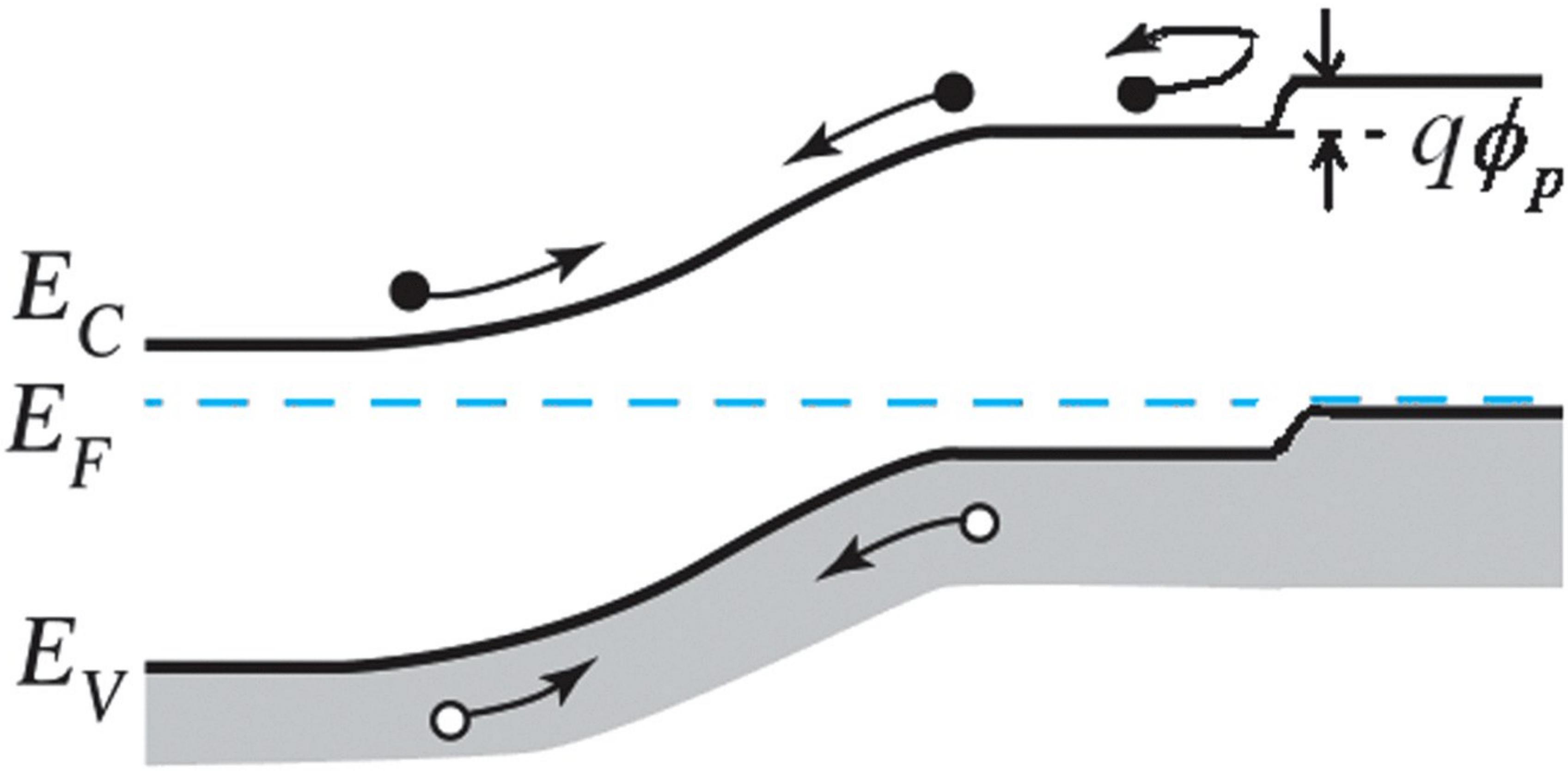
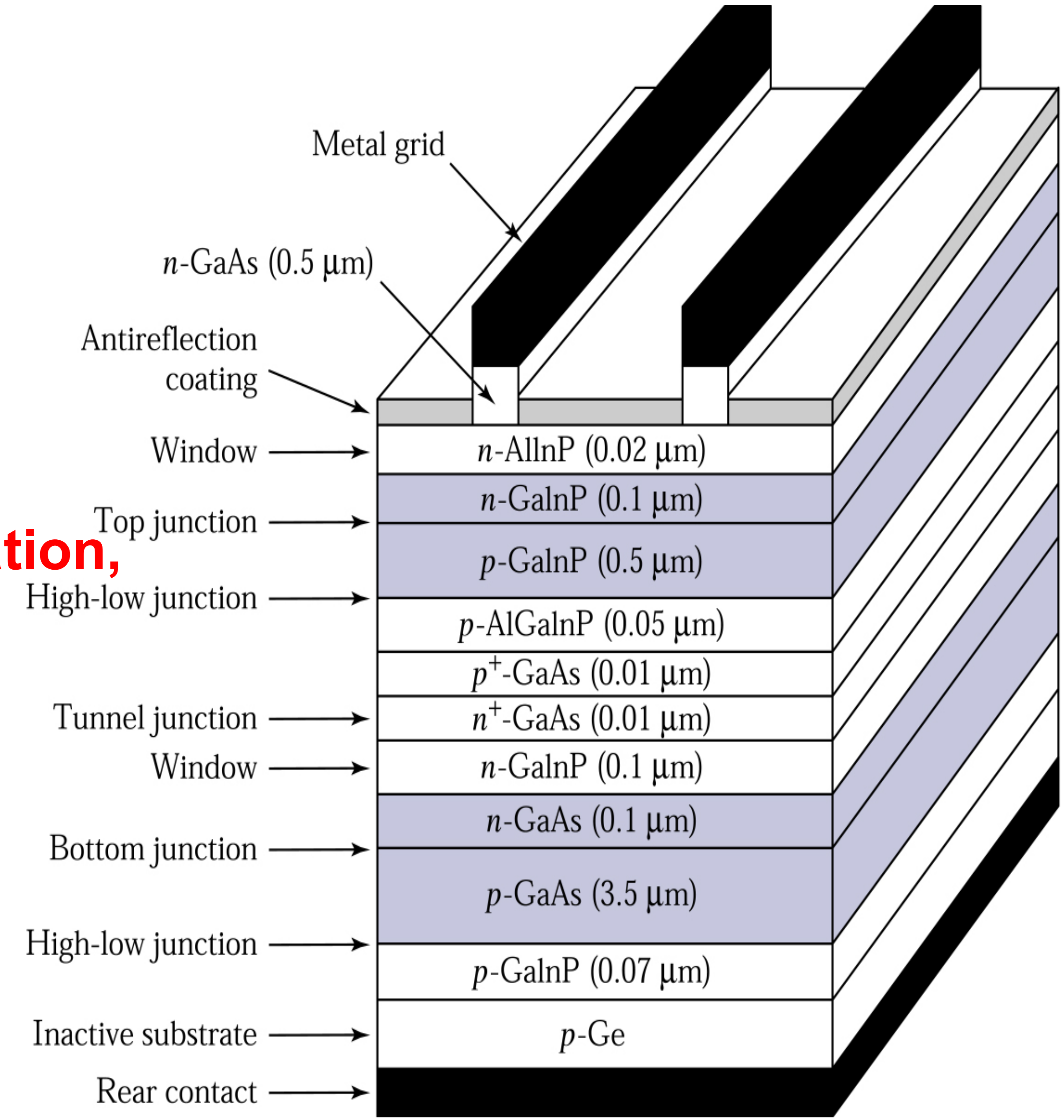



Figure 10.18b


Back-surface field

**Figure 10.19.** Monolithic tandem solar cell.[24]




**Reduce recombination, 30% efficiency**

# Lowest cost, 5% efficiency

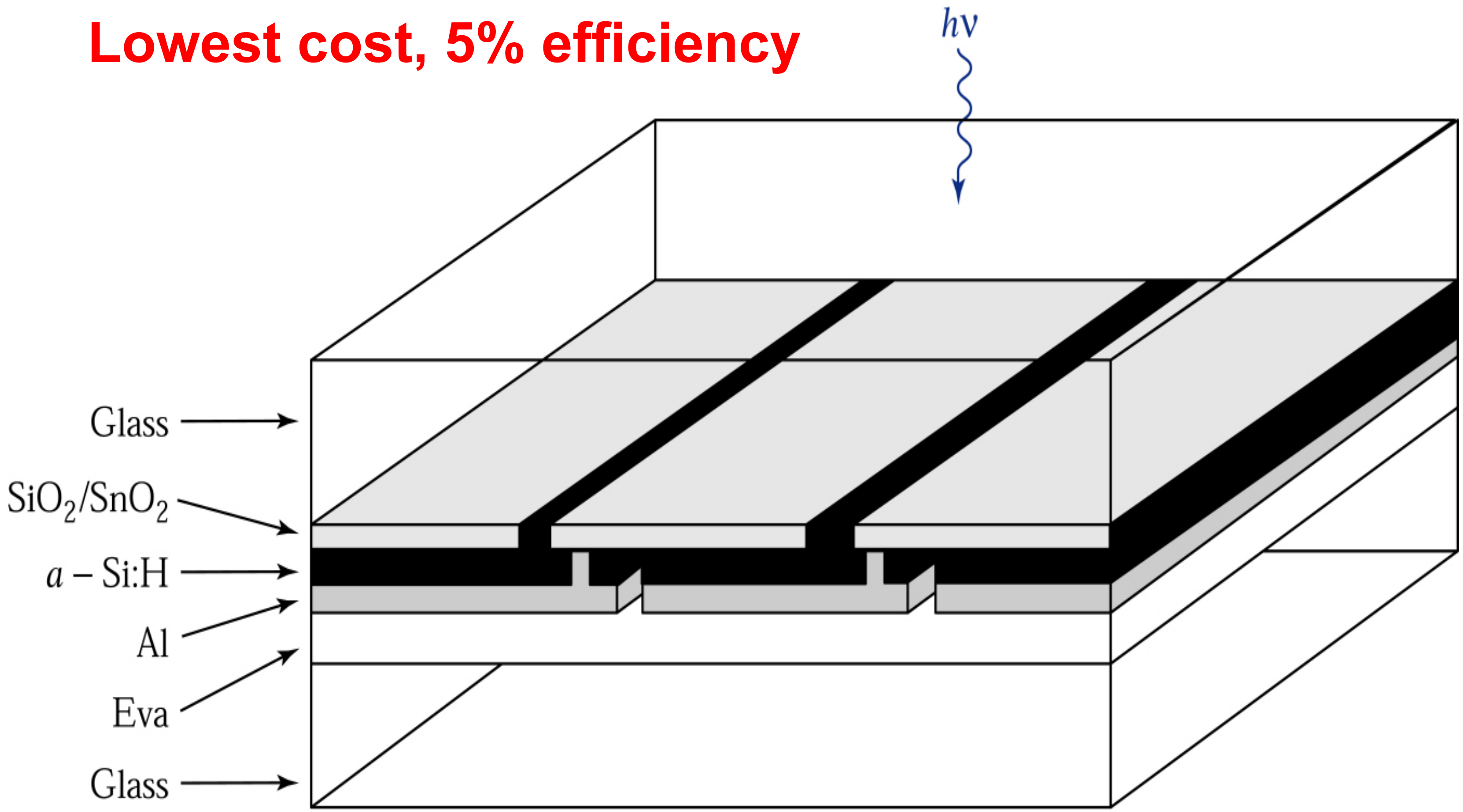



**Figure 10.20.** Series-interconnected a-SI solar cells deposited on a glass substrate with a rear glass cover bonded using ethylene vinyl acetate.

Micro-crystalline/
amorphous tandem cell

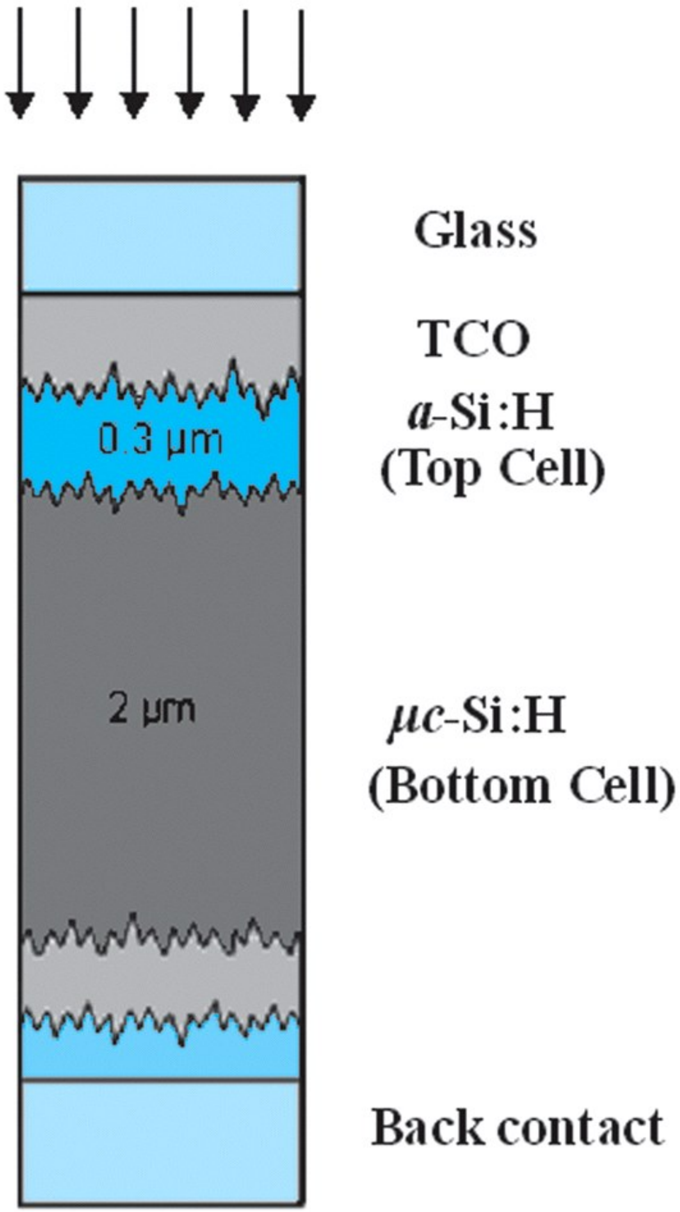



**Figure 10.21a**
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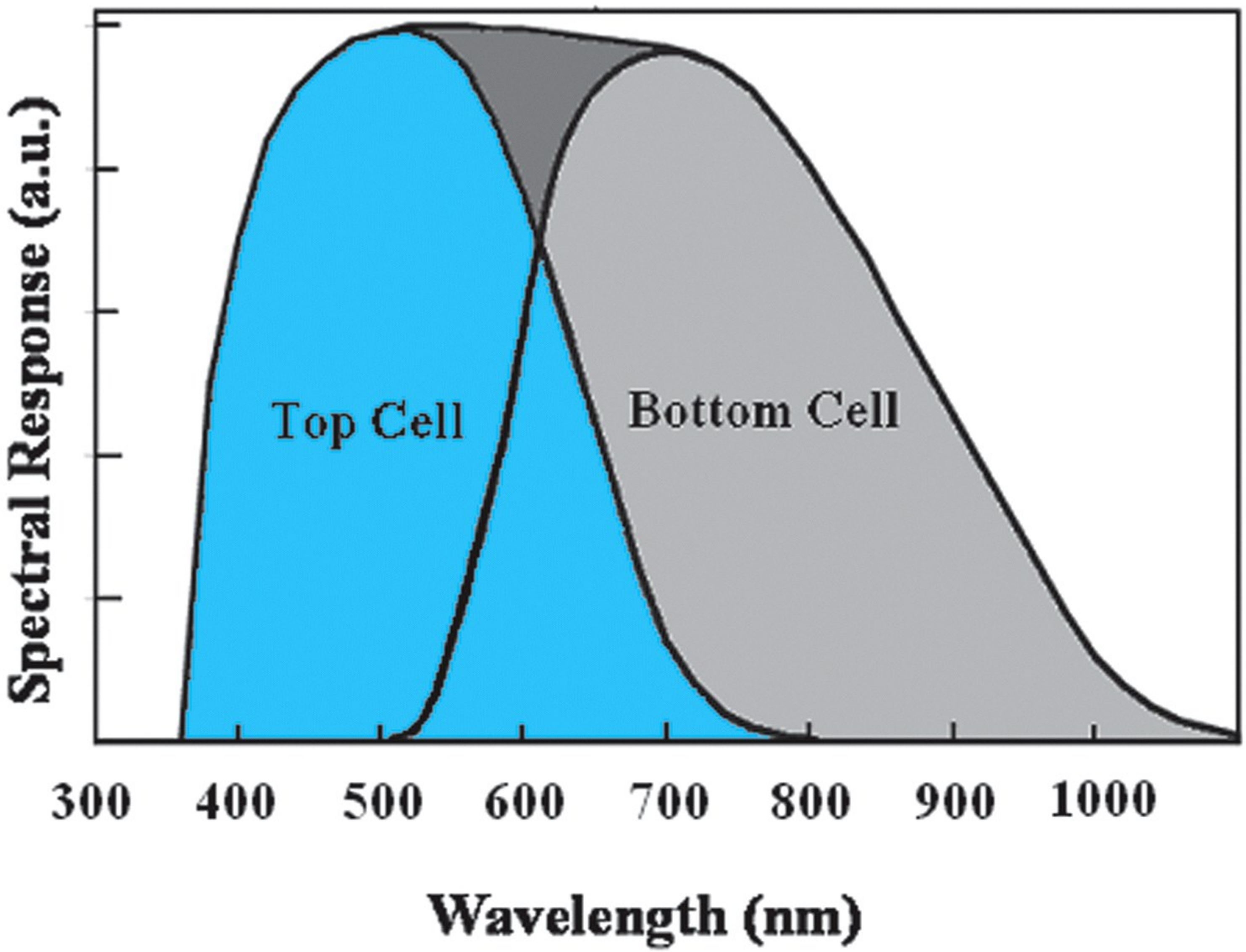


**Figure 10.21b**



Response of micro-crystalline/amorphous tandom cell

Absorption α of $CuInSe_2$

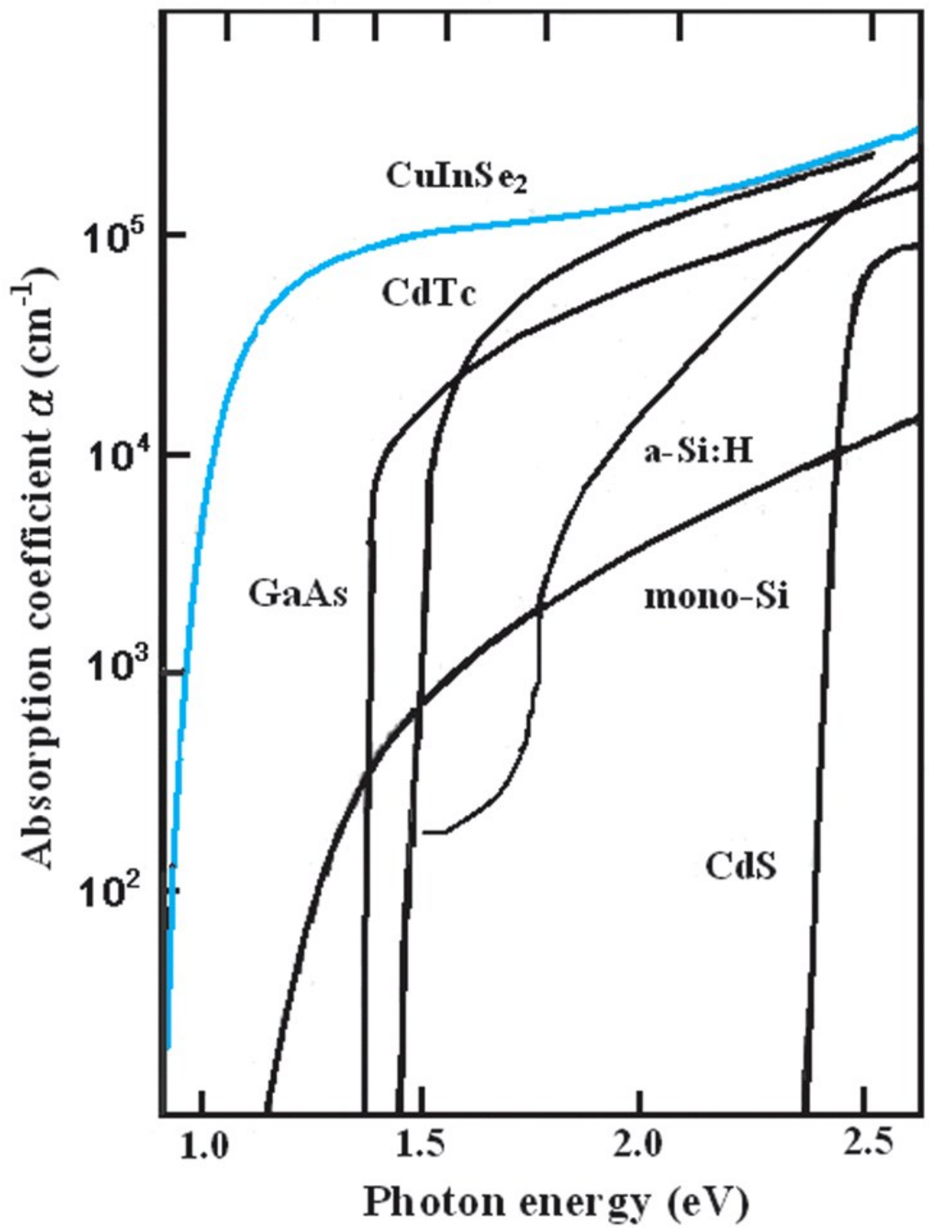


Figure 10.22a

CIGS solar cell

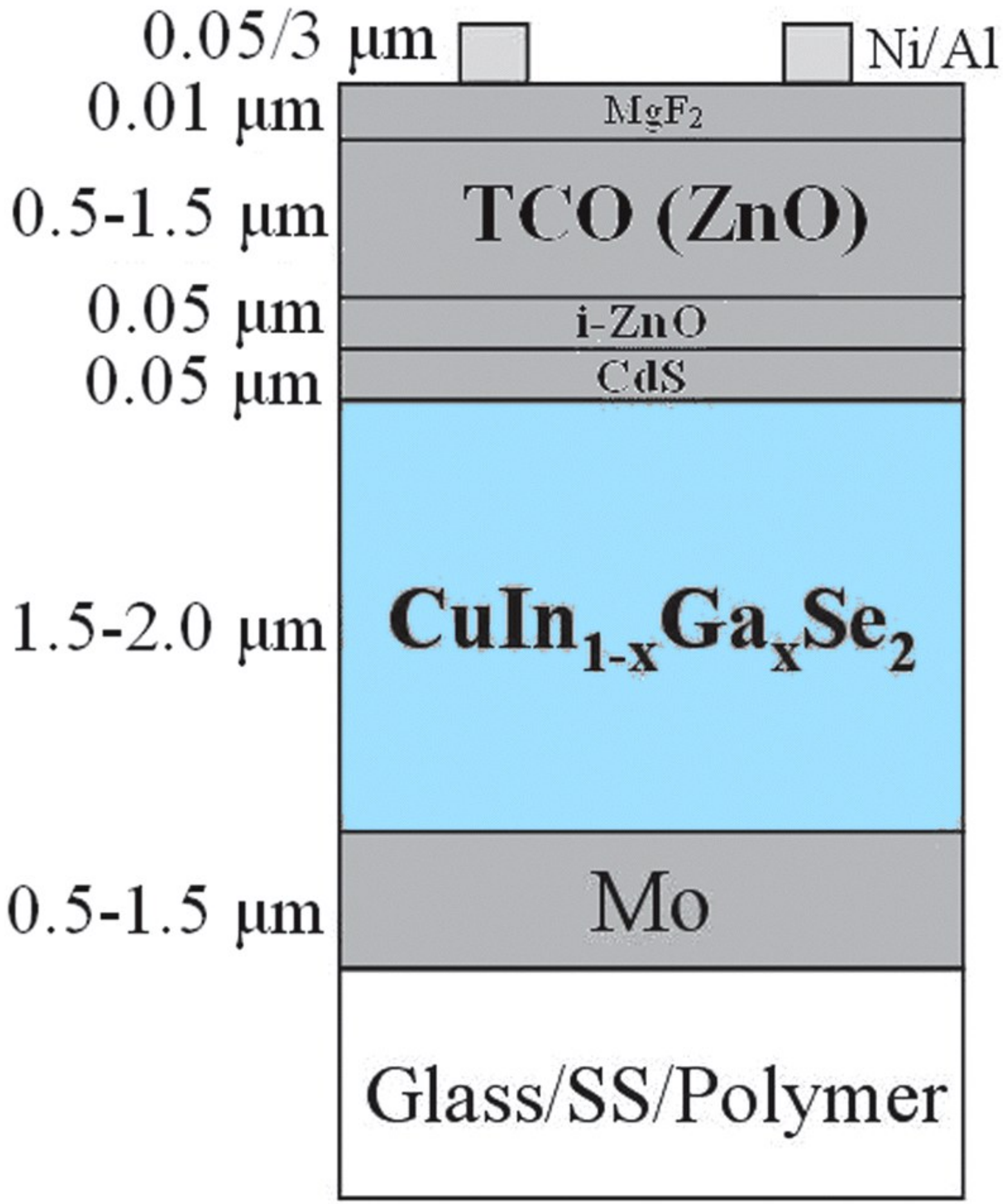


Figure 10.22b

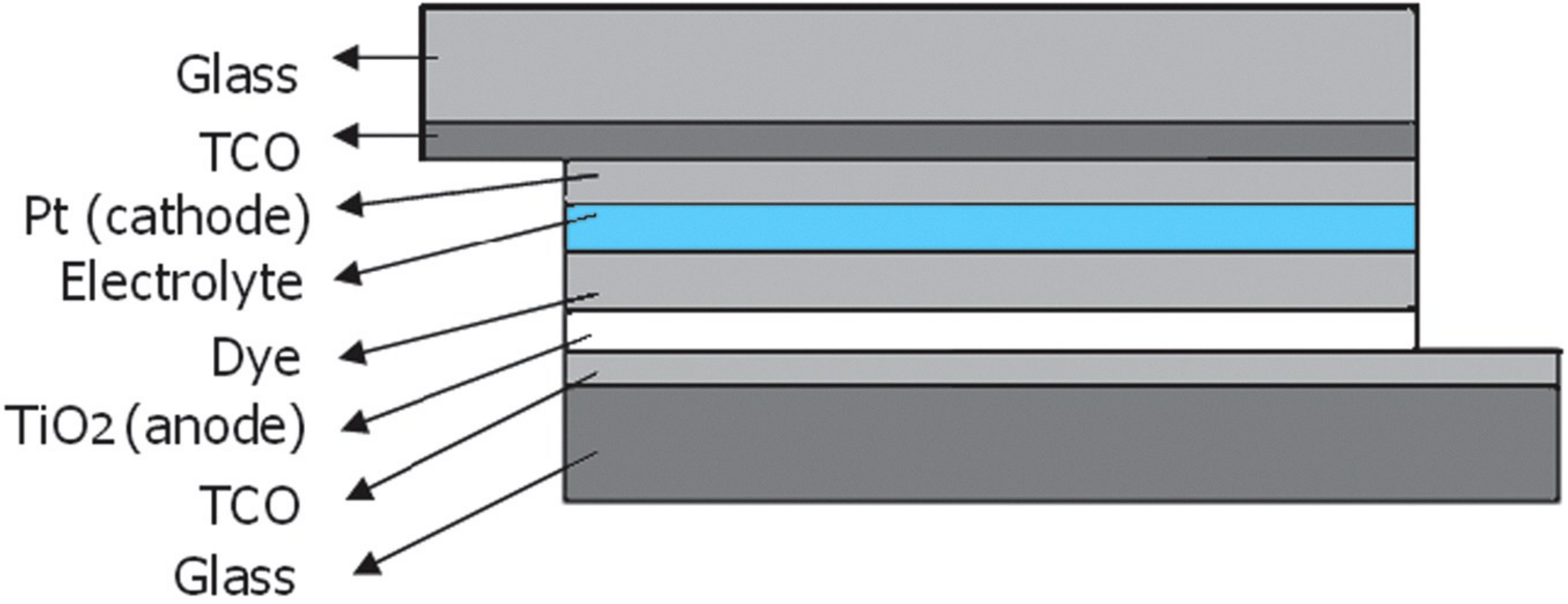


Figure 10.23a


DSSC structure

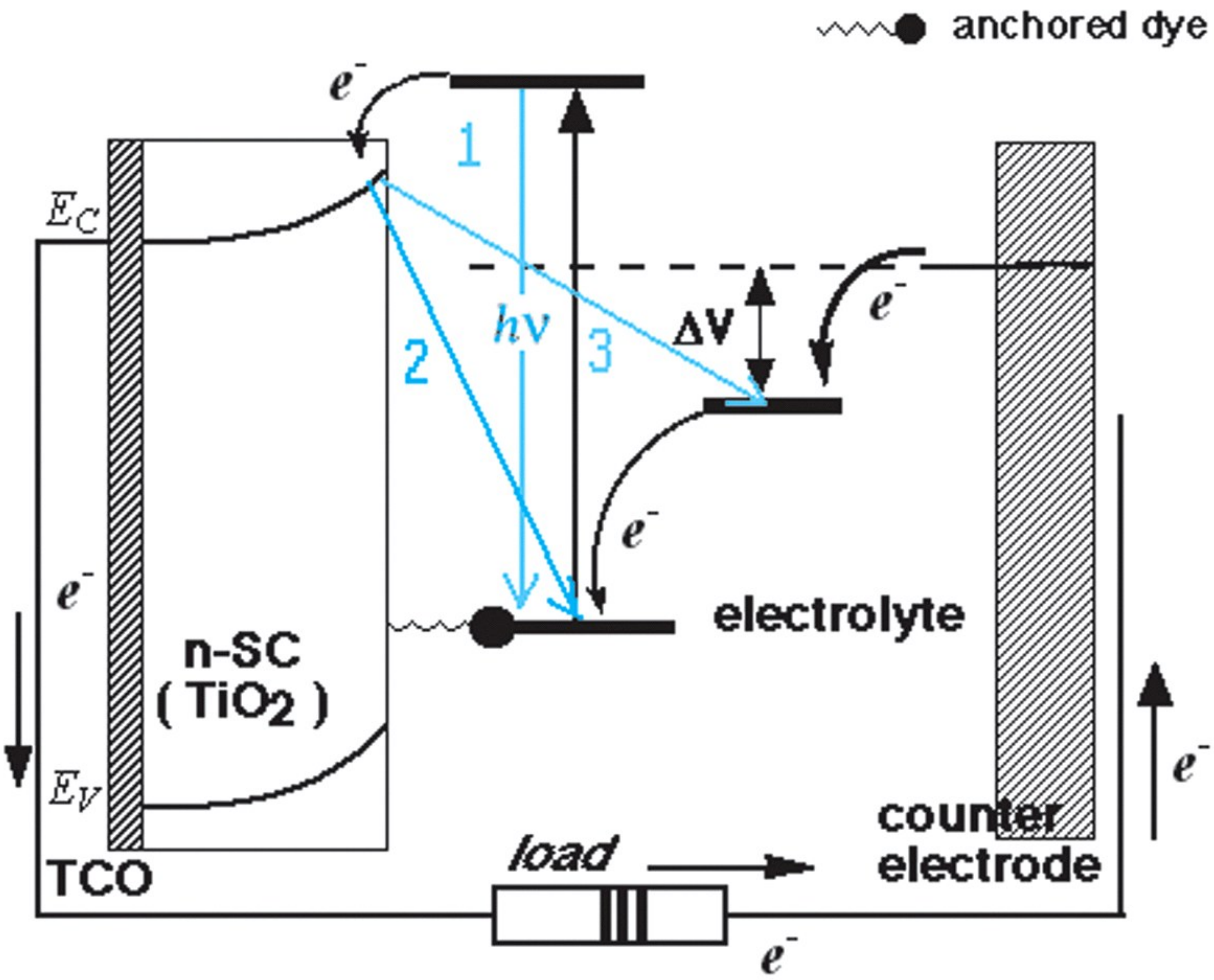


Figure 10.23b


DSSC band diagram and carrier losses

Organic solar cell, heterojunction between donor/acceptor

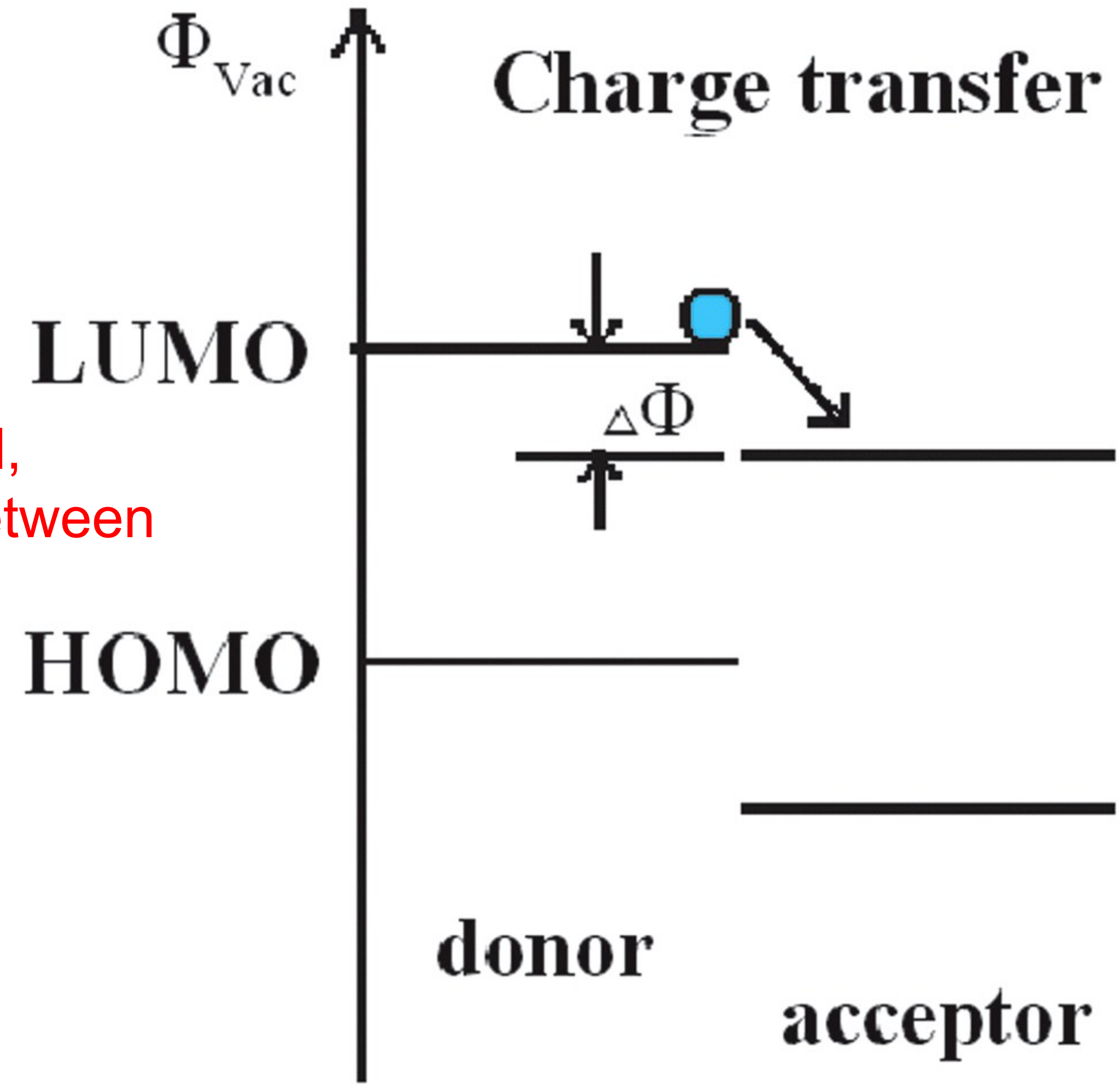


Figure 10.24

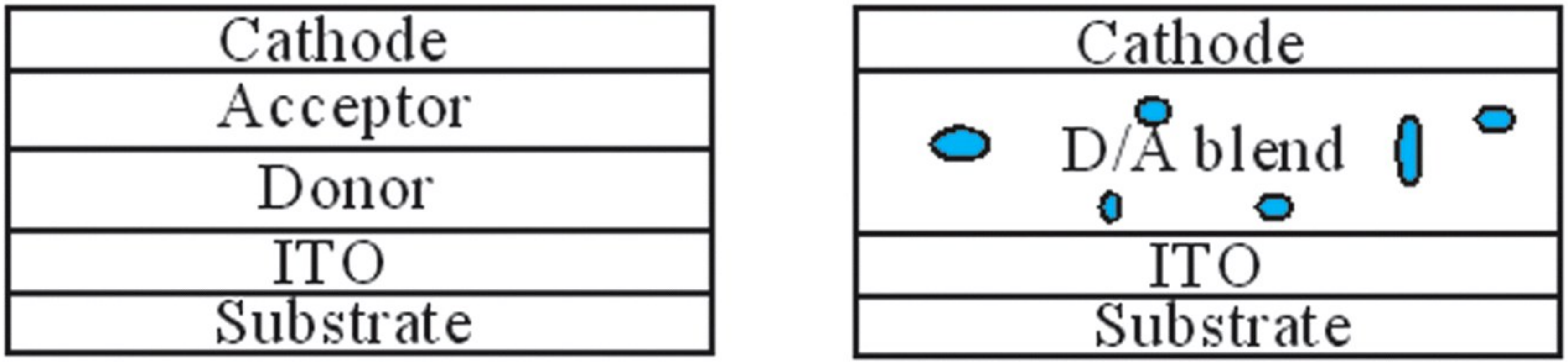


Figure 10.25



(a) bilayer, (b) bulk heterojunction

Quantum dot
solar cell

Carrier transport
through minband,
a higher potential

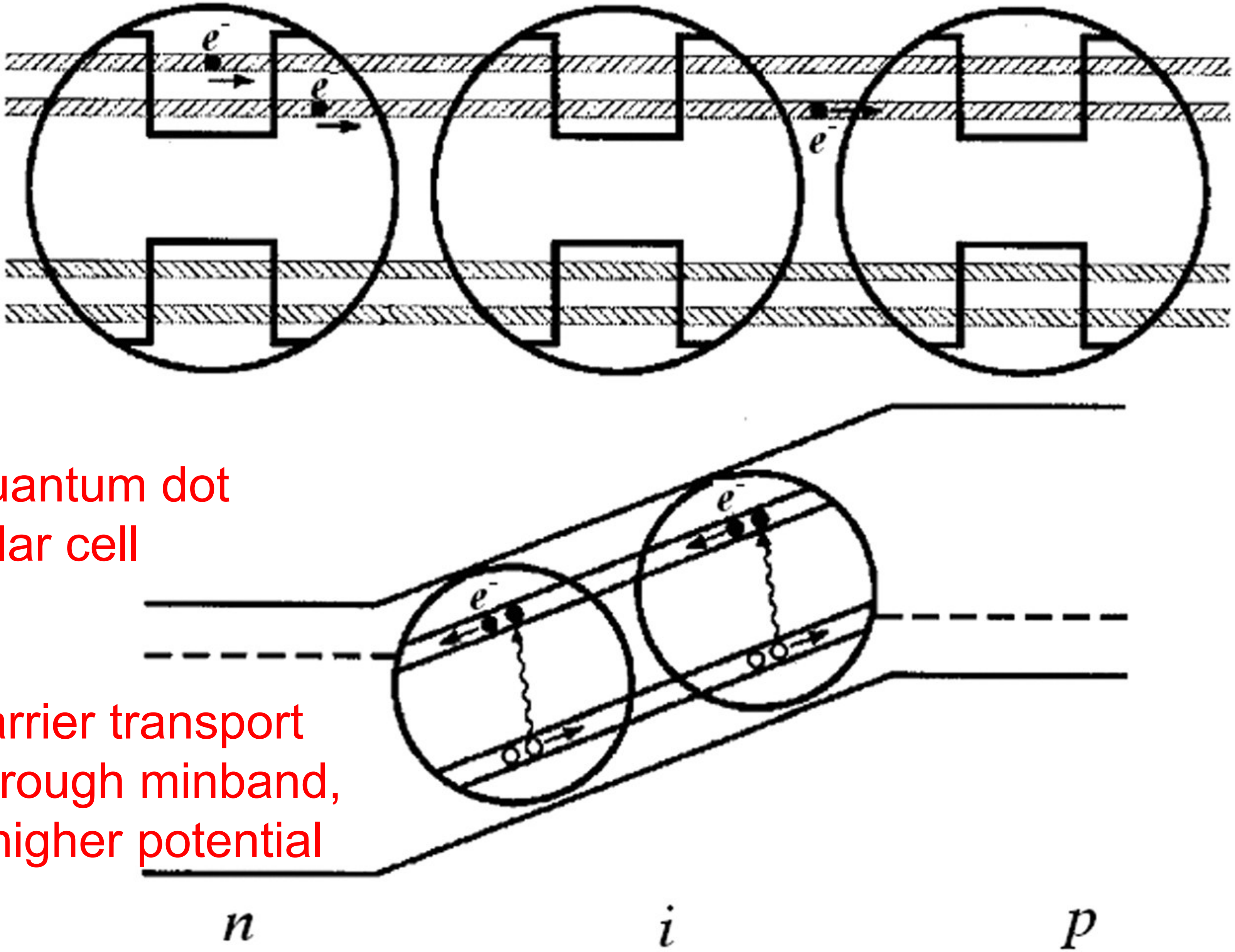


**Figure 10.26a**
**Reprinted from *Physica E: Low-Dimensional Systems and Nanostructures*, 14, A.J. Nozik, "Quantum dot solar cells", pp. 115-120, Copyright 2002, with permission from Elsevier.**

Impact ionization enhances efficiency

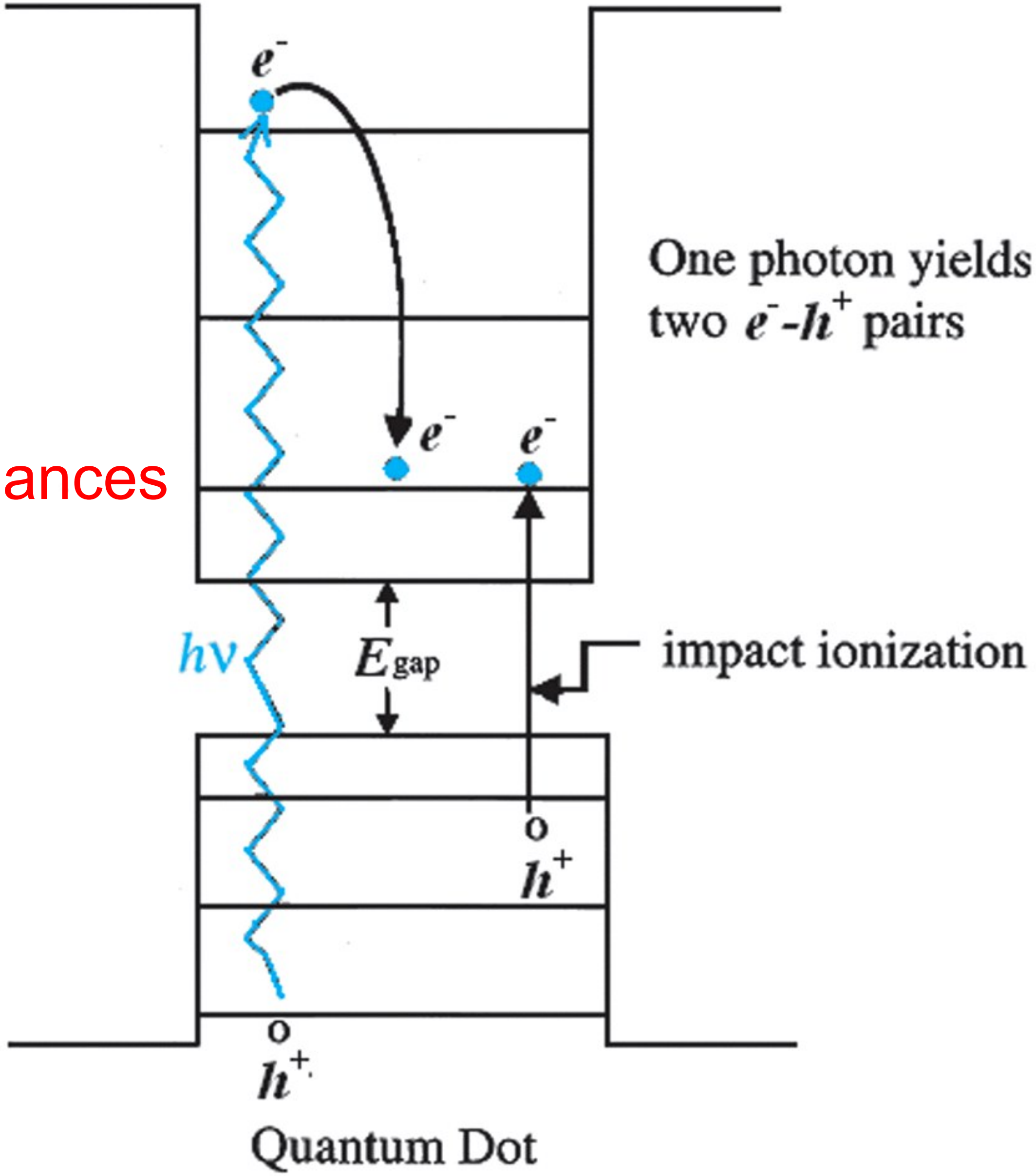


Figure 10.26b
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Efficiency, open-circuit voltage, short-circuit current, and fill factor versus **solar concentration.**[30]

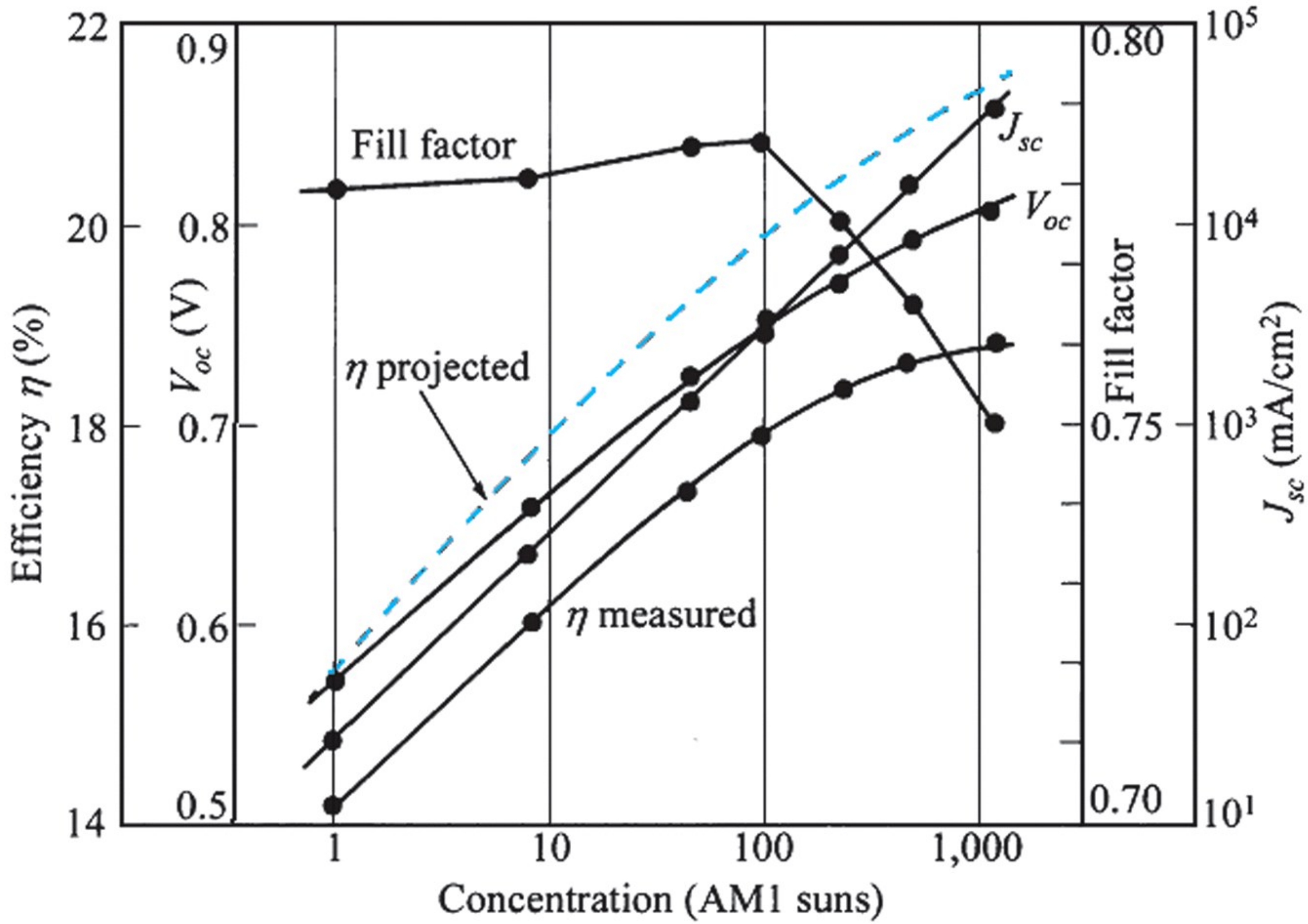


Figure 10.27



聚光increase η ,Voc 等優點 強度上升1E3