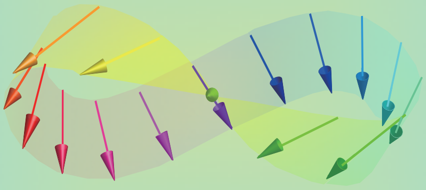
Semiconductor Devices 24



Atsufumi Hirohata

Department of Electronics

The University of York

11:00 Thursday, 27/November/2014 (P/T 005)

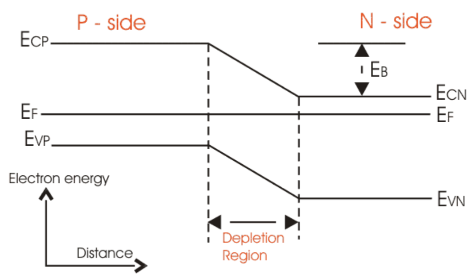
Exercise 3

Calculate the built-in potential of an abrupt *p*-*n* junction diode which is made from Silicon and has the following properties:

p-region: doping density of $N_A = 2 \times 10^{21}$ m^{-3}
n-region: doping density of $N_D = 1 \times 10^{21}$ m^{-3}
intrinsic concentration of electrons:

$$n_i = 1.2 \times 10^{16} \text{ m}^{-3}$$

and assume $k_B T / q = 25$ mV.



Answer to Exercise 3

The built-in potential is defined as

$$V_{bi} =$$

By substituting the given values into the above relationship,

$$V_{bi} = 25[\mathrm{mV}] \cdot \ln\left(\frac{2 \times 10^{21}[\mathrm{m}^{-3}] \cdot 1 \times 10^{21}[\mathrm{m}^{-3}]}{\left(1.2 \times 10^{16}[\mathrm{m}^{-3}]\right)^2} \right)$$

$$= 25[\mathrm{mV}] \cdot \ln\left(1.66 \times 10^{10}\right)$$

$$= 25[\mathrm{mV}] \cdot 23.5$$

$$\approx$$

24 Bias Application

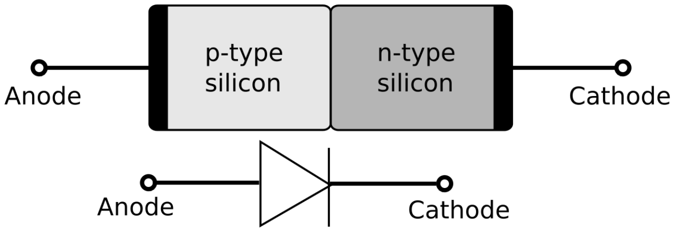
- Forward bias
- Reverse bias
- Current rectification
- Junction breakdown

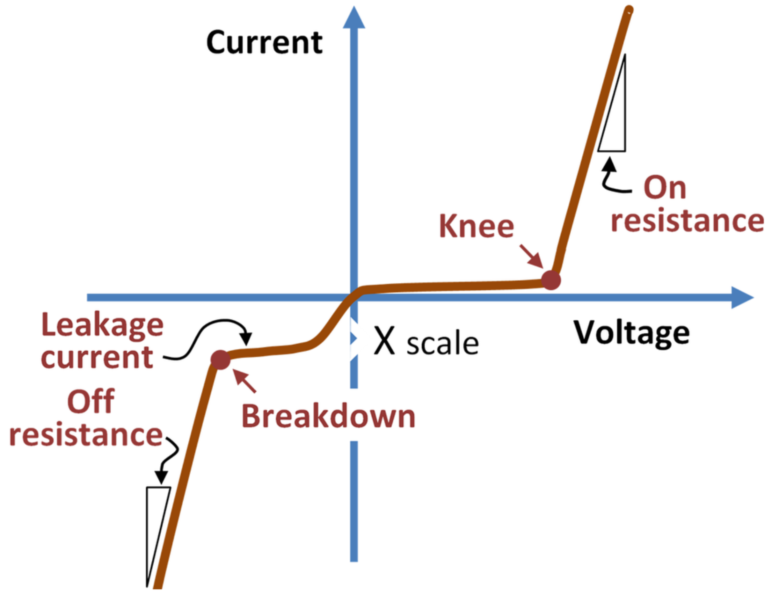
p-n Diode

A junction made by attaching *p*- and *n*-doped semiconductors :

Widely used to insulate transistors.

Common circuit to convert ac to dc in a battery charger.

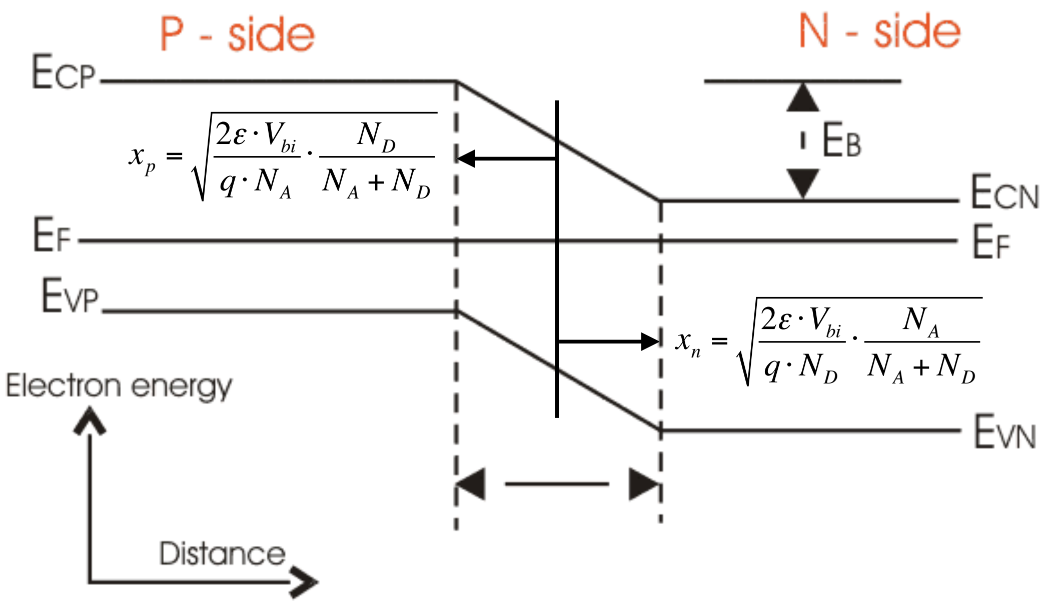




* http://www.wikipedia.org/

Band Diagram

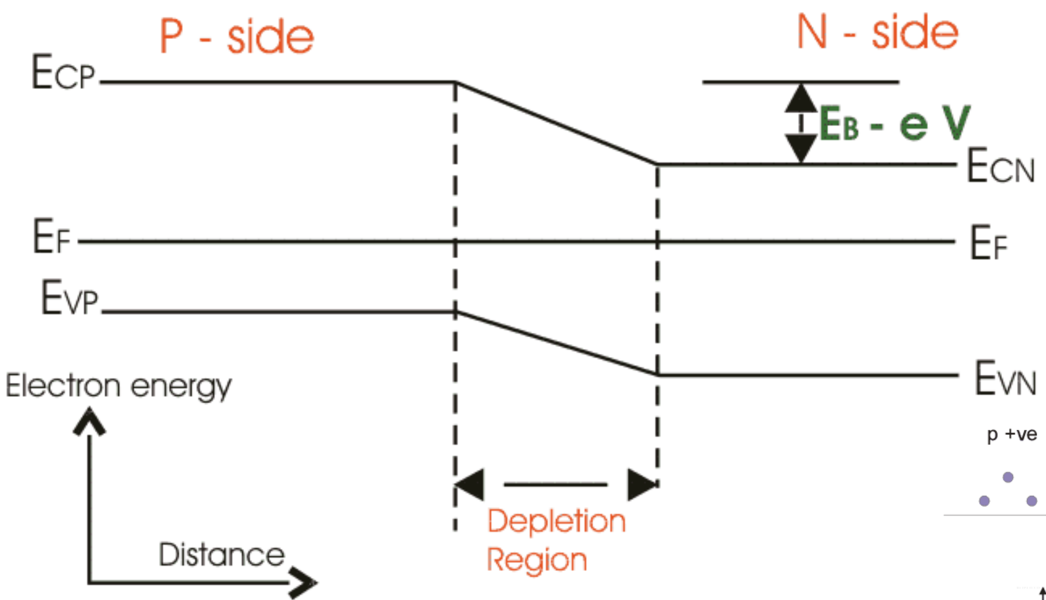
Without a bias voltage :

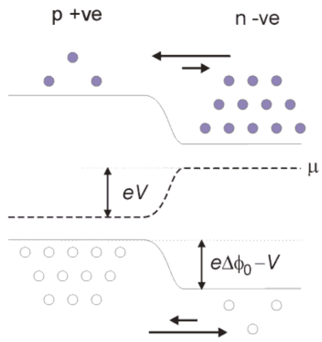


* http://www.electrical4u.com/p-n-junction-diode/

Band Diagram under a Forward Bias

Forward bias application :

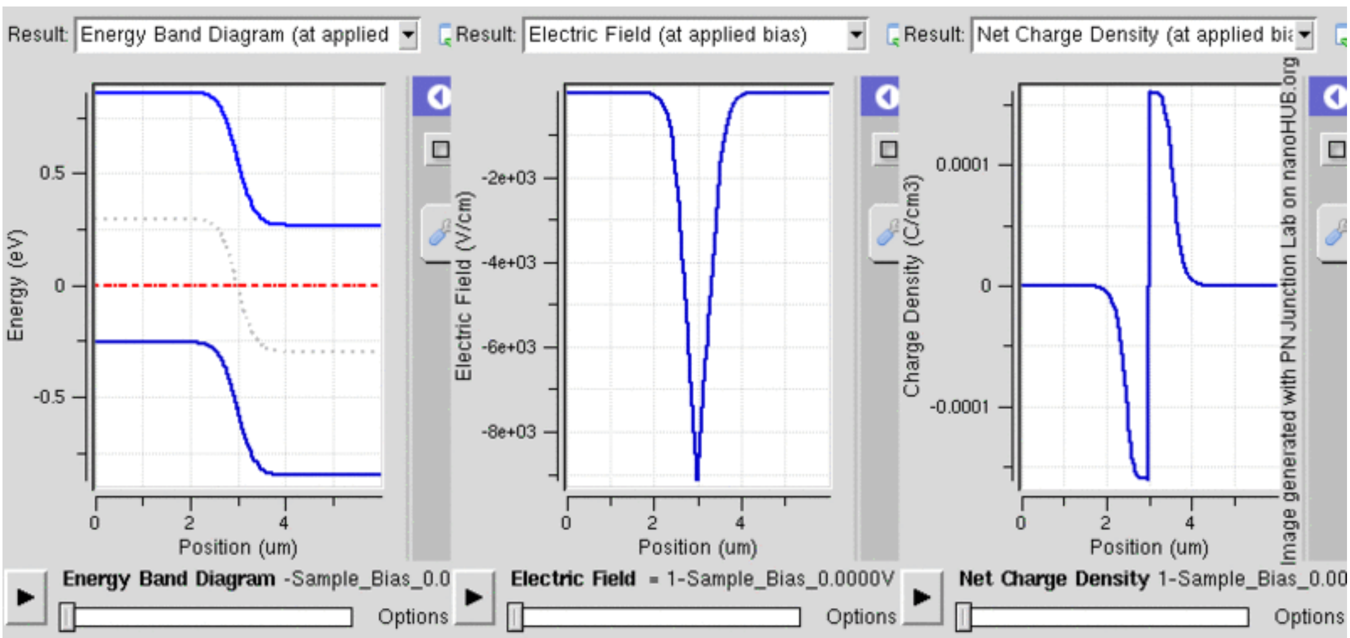




* http://www.electrical4u.com/p-n-junction-diode/;
** http://britneyspears.ac/physics/pn/pnjunct.htm

Forward Bias Application

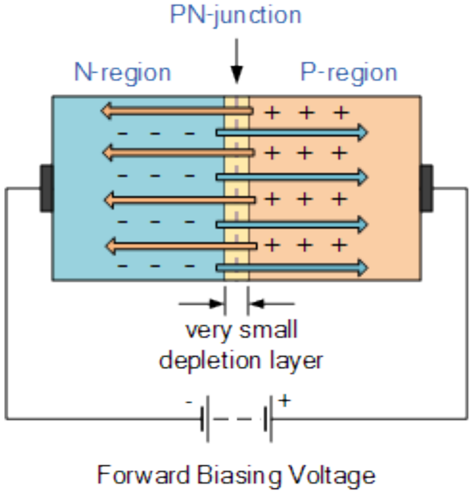
Energy, electric field and charge density :

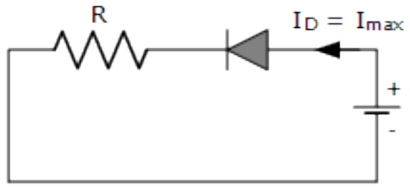


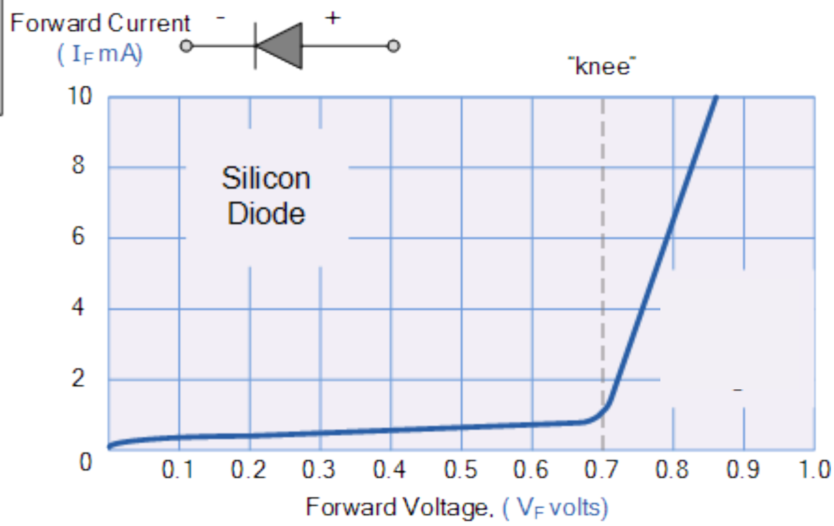
* http://www.wikipedia.org/

Forward Bias Region

(   ) depletion layer :



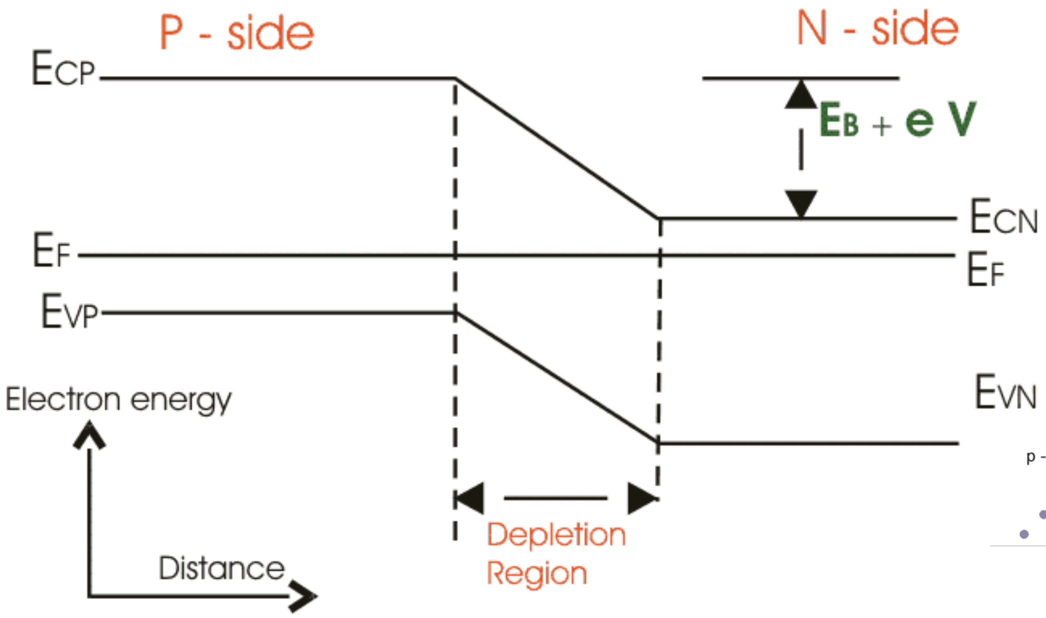


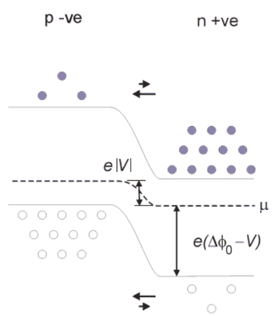


* http://www.electronics-tutorials.ws/diode/diode_3.html

Band Diagram under a Reverse Bias

Reverse bias application :

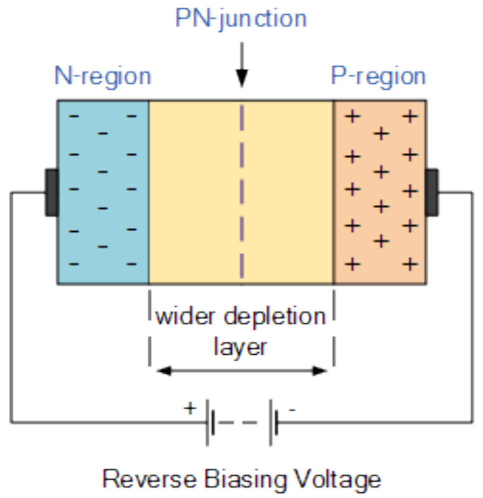


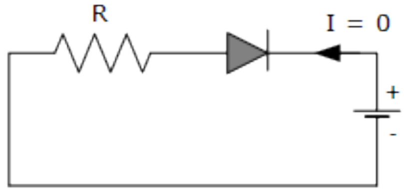


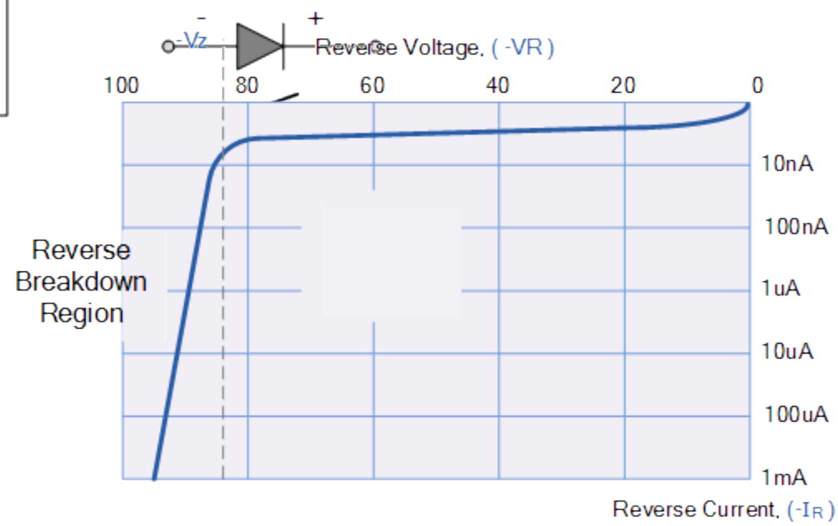
* http://www.electrical4u.com/p-n-junction-diode/;
** http://britneyspears.ac/physics/pn/pnjunct.htm

Reverse Bias Region

(   ) depletion layer :



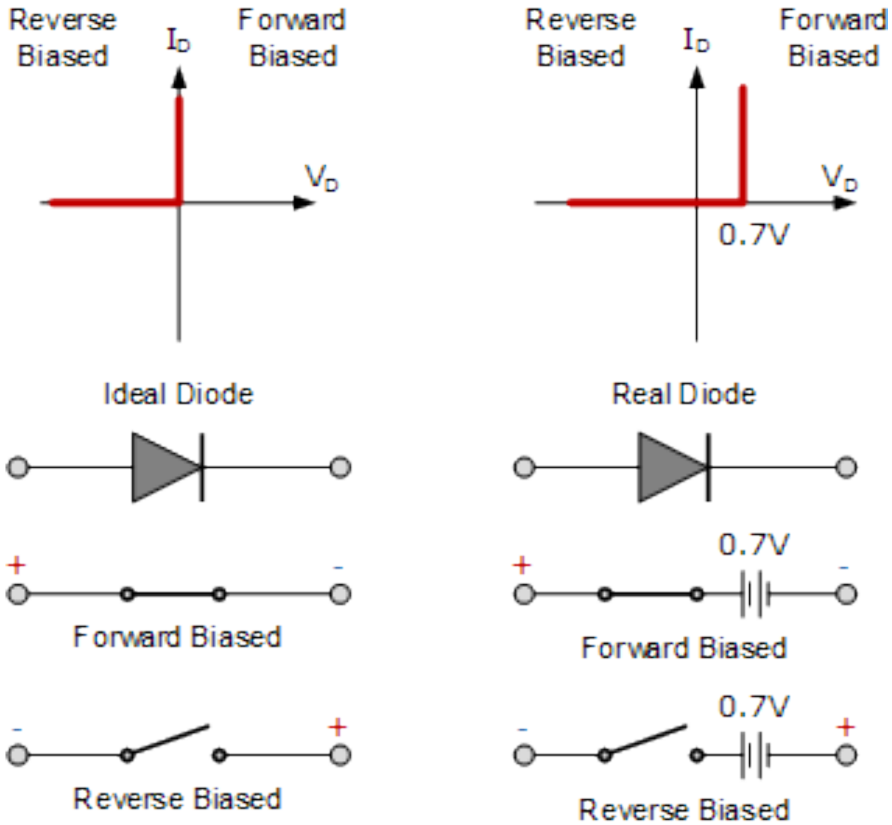




* http://www.electronics-tutorials.ws/diode/diode_3.html

Ideal and Real *p-n* Diodes

Current-voltage characteristics :



* http://www.electronics-tutorials.ws/diode/diode_3.html

p-n Junction Interface

By connecting *p*- and *n*-type semiconductors,
http://kccn.konan-u.ac.jp/physics/semiconductor/diagram/a08.html

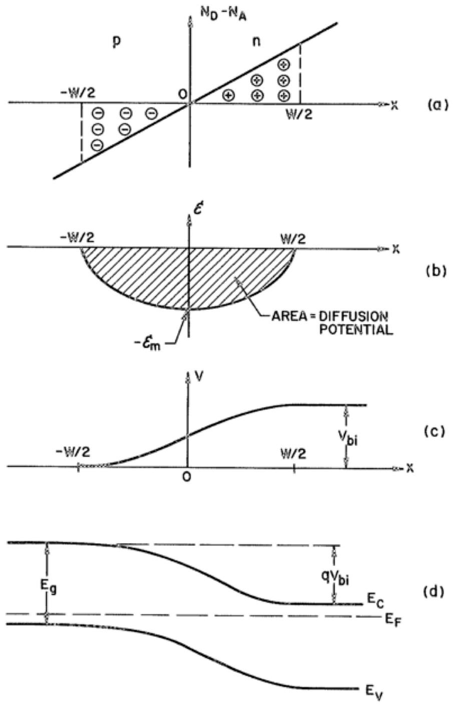


Fig. 15 Linearly graded junction in thermal equilibrium. (*a*) Space-charge distribution. (*b*) Electric field distribution. (*c*) Potential variation with distance. (*d*) Energy-band diagram.

* S. M. Sze, *Physics of Semiconductor Devices* (Wiley, New York, 2006).

Rectification in a *p-n* Junction

Under an electrical field ***E***,

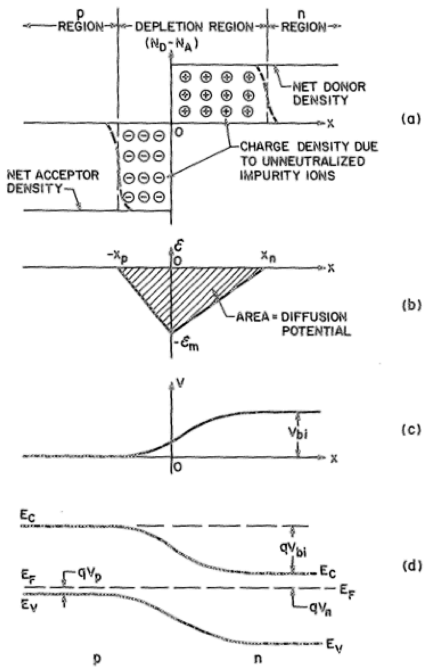


Fig. 10 Abrupt *p-n* junction in thermal equilibrium. (*a*) Space-charge distribution. The dashed lines indicate the majority-carrier distribution tails. (*b*) Electric field distribution. (*c*) Potential variation with distance where V_{bi} is the built-in potential. (*c*) Energy-band diagram.

Current rectification :

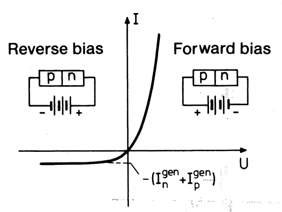
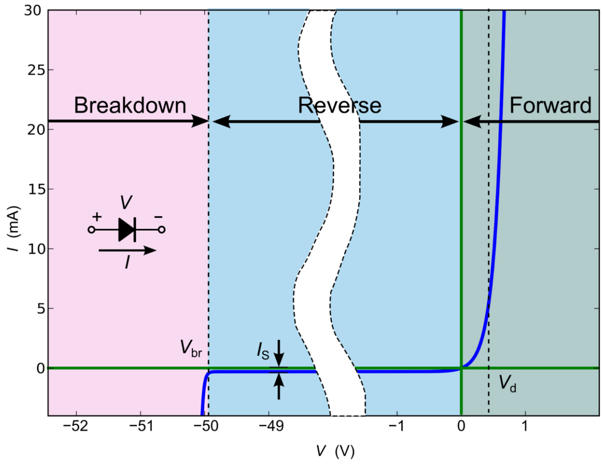


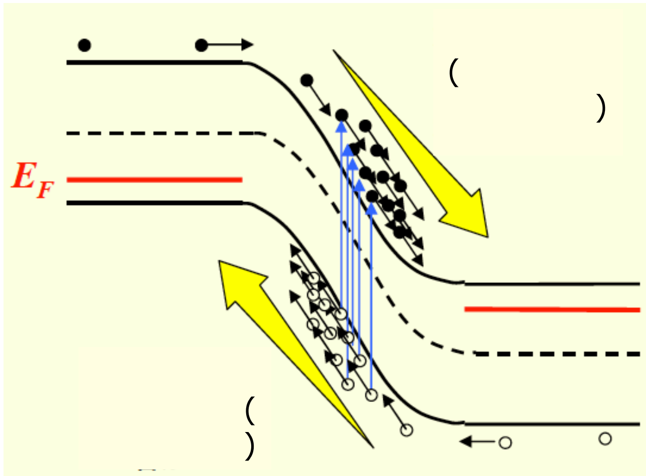
Fig. 12.18. Schematic representation of the current voltage (*I–U*) characteristic of a *p–n* junction, together with the corresponding circuit. The maximum current in the reverse direction is given by the sum of the generation currents for electrons and holes

Sze, *Physics of Semiconductor Devices* (Wiley, New York, 2006);
** H. Ibach and H. Lüth, *Solid-State Physics* (Springer, Berlin, 2003).

Junction Breakdown

Electron avalanche :

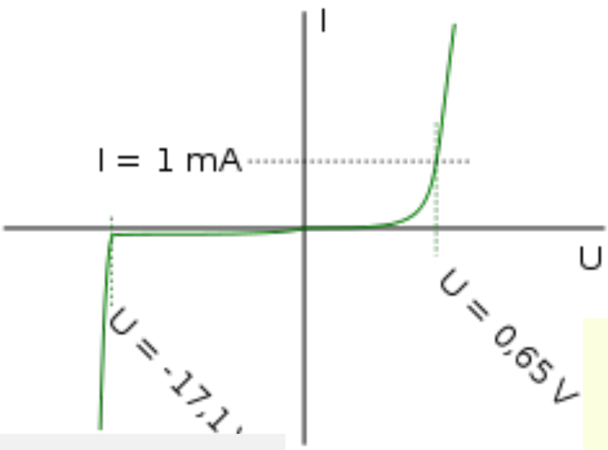


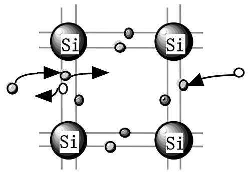


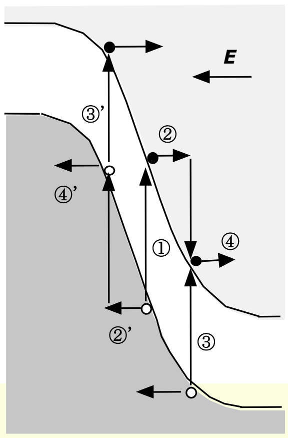
* http://www.wikipedia.org/;
** http://www.ritsumei.ac.jp/se/re/fujinolab/semicon/semicon8.pdf

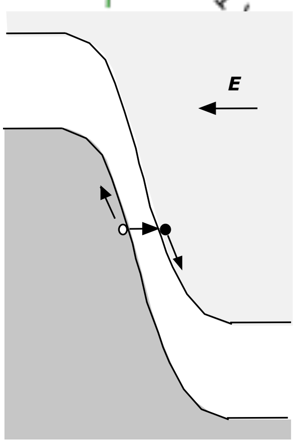
Junction Breakdown

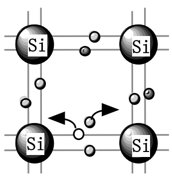
Zener diode :

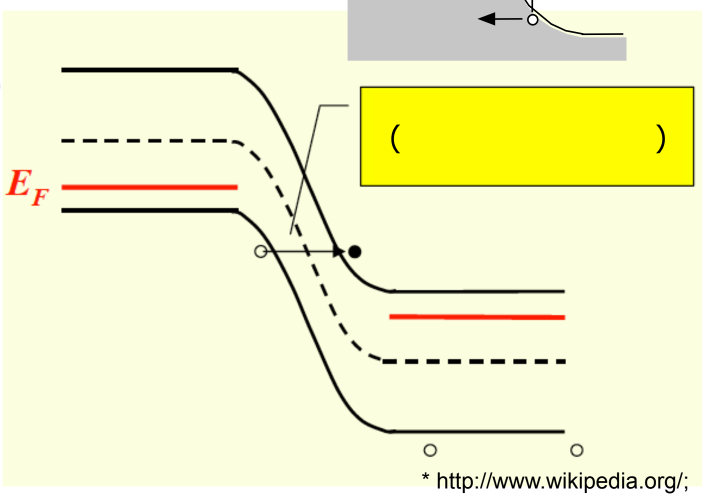








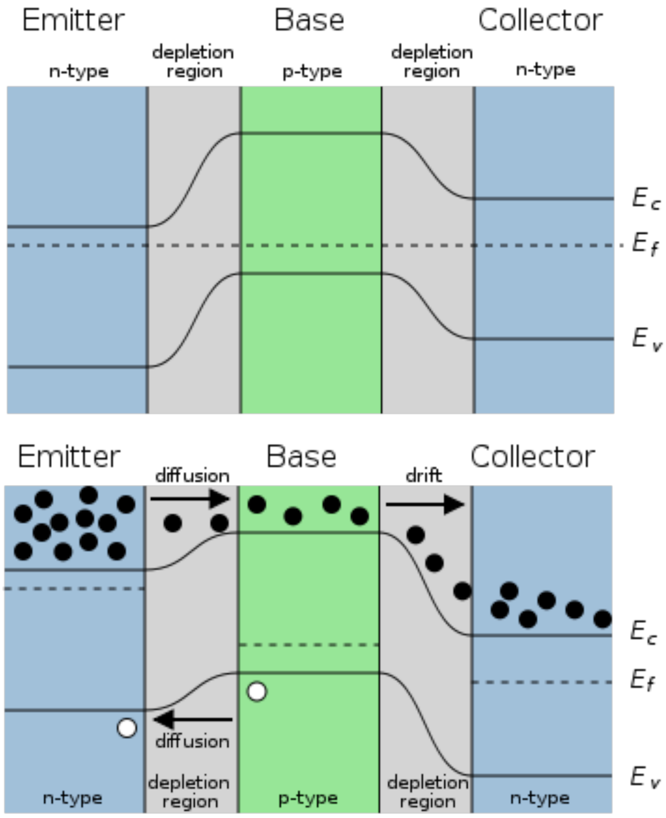


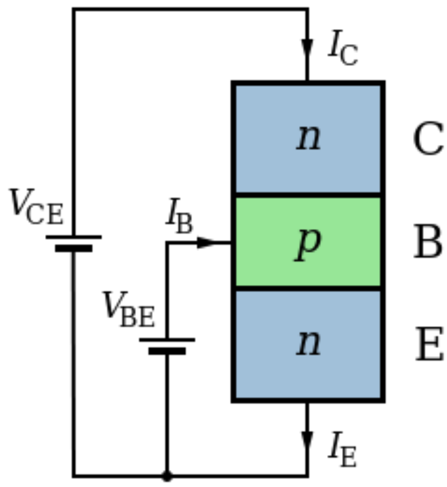


* http://www.wikipedia.org/;
** http://www.ritsumei.ac.jp/se/re/fujinolab/semicon/semicon8.pdf;
*** www.tc.knct.ac.jp/~hayama/denshi/chapter3.ppt

Bipolar Transistors

npn junction :

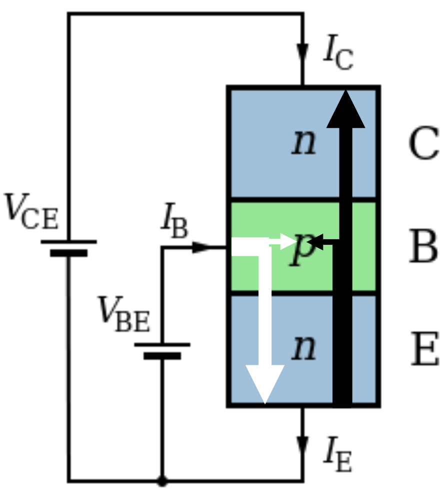




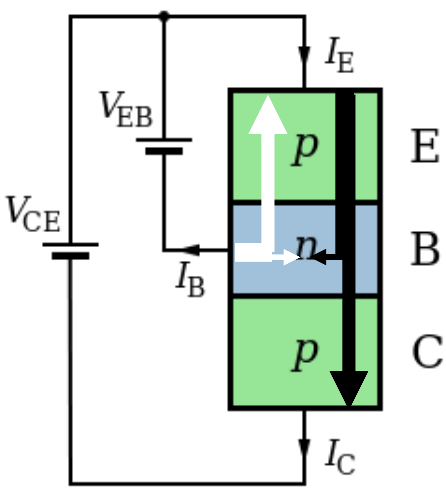
* http://www.wikipedia.org/

Bipolar Transistors

npn junction :



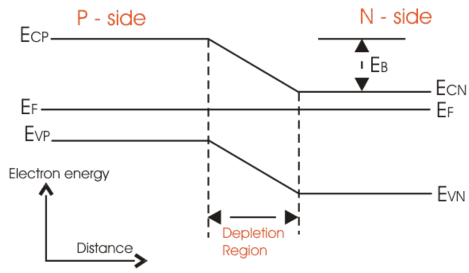
pnp junction :



* http://www.wikipedia.org/

Exercise 4

Calculate the depletion layer width of an abrupt *p*-*n* junction diode which is made from Silicon and has the following properties:



p-region: doping density of $N_A = 2 \times 10^{21}$ m^{-3}

n-region: doping density of $N_D = 1 \times 10^{21}$ m^{-3}

permittivity: $\varepsilon = \varepsilon \times \varepsilon_0 = 12.0 \times 8.854 \times 10^{-12}$ F/m

and $q = 1.6 \times 10^{-19}$ C.