# CPV追日系統原理與技術

CPV Solar Tracking Principle and Technology

(OE_10330)

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2015-10-16 (Friday)

14:10-17:00

(Contents are solely for educational purpose)

# 聚光型太陽能電池片

1. 效率極限
   1. 太陽光光譜
   2. 耗損種類
2. 疊層結構太陽能電池
   1. 疊層結構設計
   2. 疊層結構內部層次功能組成
      1. 穿隧介面
      2. 窗面
      3. 前後面場層
   3. 穿隧二極體
   4. 磊晶技術

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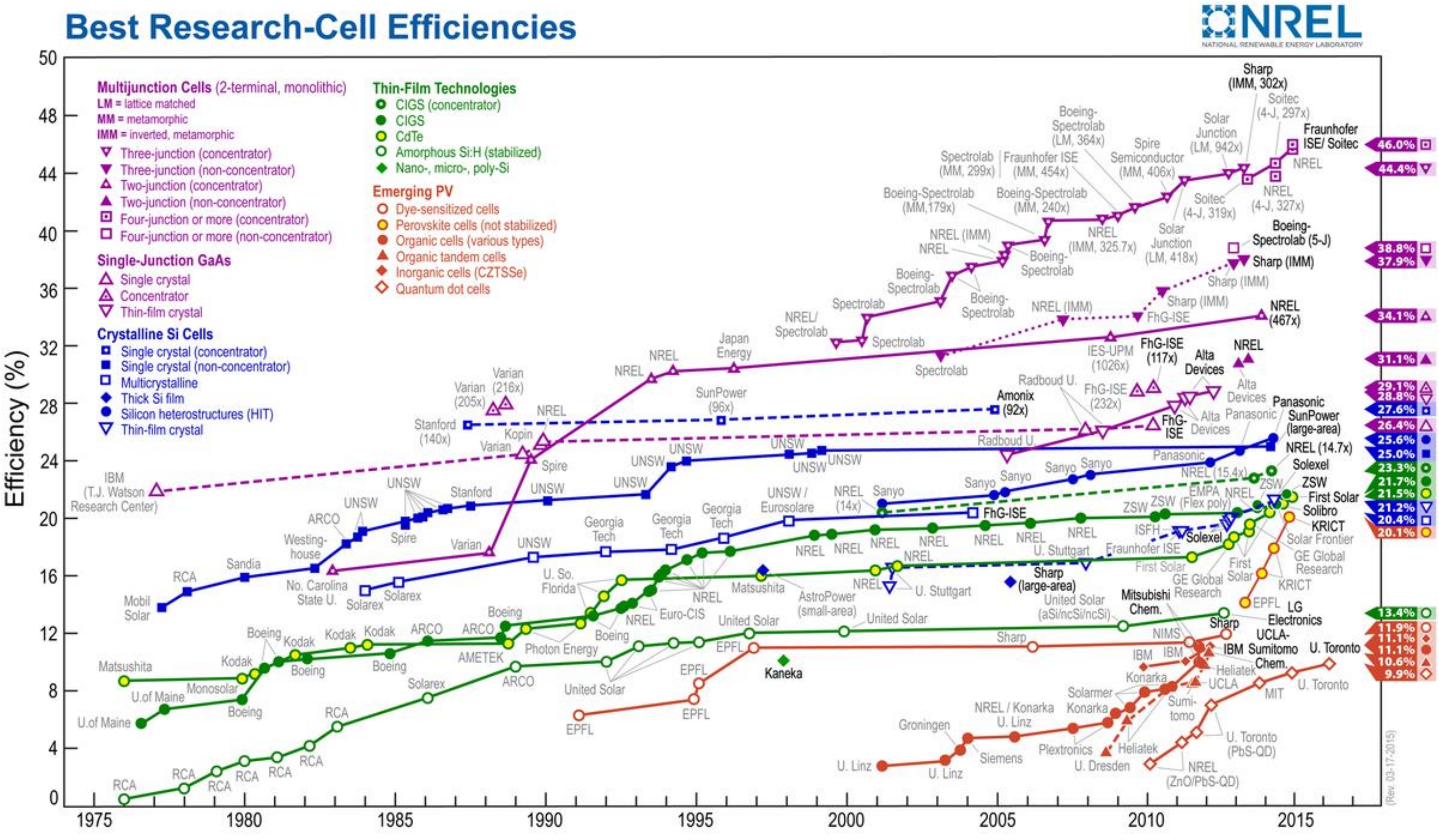


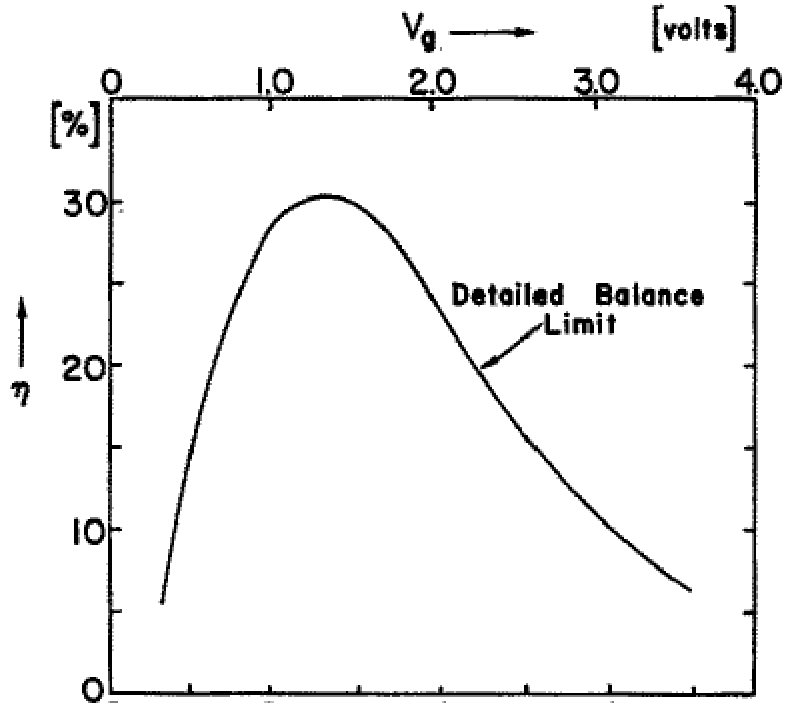

"Best Research-Cell Efficiencies" by National Renewable Energy Laboratory (NREL) - National Renewable Energy Laboratory (NREL), Golden, CO – United States Department of Energywebsiteimageexplanatory notes. Licensed under Public Domain via Wikimedia Commons - http://commons.wikimedia.org/wiki/File:Best_Research-Cell_Efficiencies.png#/media/File:Best_Research-Cell_Efficiencies.png

# About Shockley-Queisser limit

JOURNAL OF APPLIED PHYSICS VOLUME 32, NUMBER 3 MARCH, 1961

**Detailed Balance Limit of Efficiency of *p-n* Junction Solar Cells***

WILLIAM SHOCKLEY AND HANS J. QUEISSER
*Shockley Transistor, Unit of Clevite Transistor, Palo Alto, California*
(Received May 3, 1960; in final form October 31, 1960)




**Shockley W, Queisser HJ. Detailed Balance Limit of Efficiency of p-n Junction Solar Cells. Journal of Applied Physics [Internet]. 1961 ;32:510-519. Available from: [http://link.aip.org/link/?JAP/32/510/1](http://link.aip.org/link/?JAP/32/510/1)**

**[Steve Byrnes's Homepage]()**

http://sjbyrnes.com/?page_id=15

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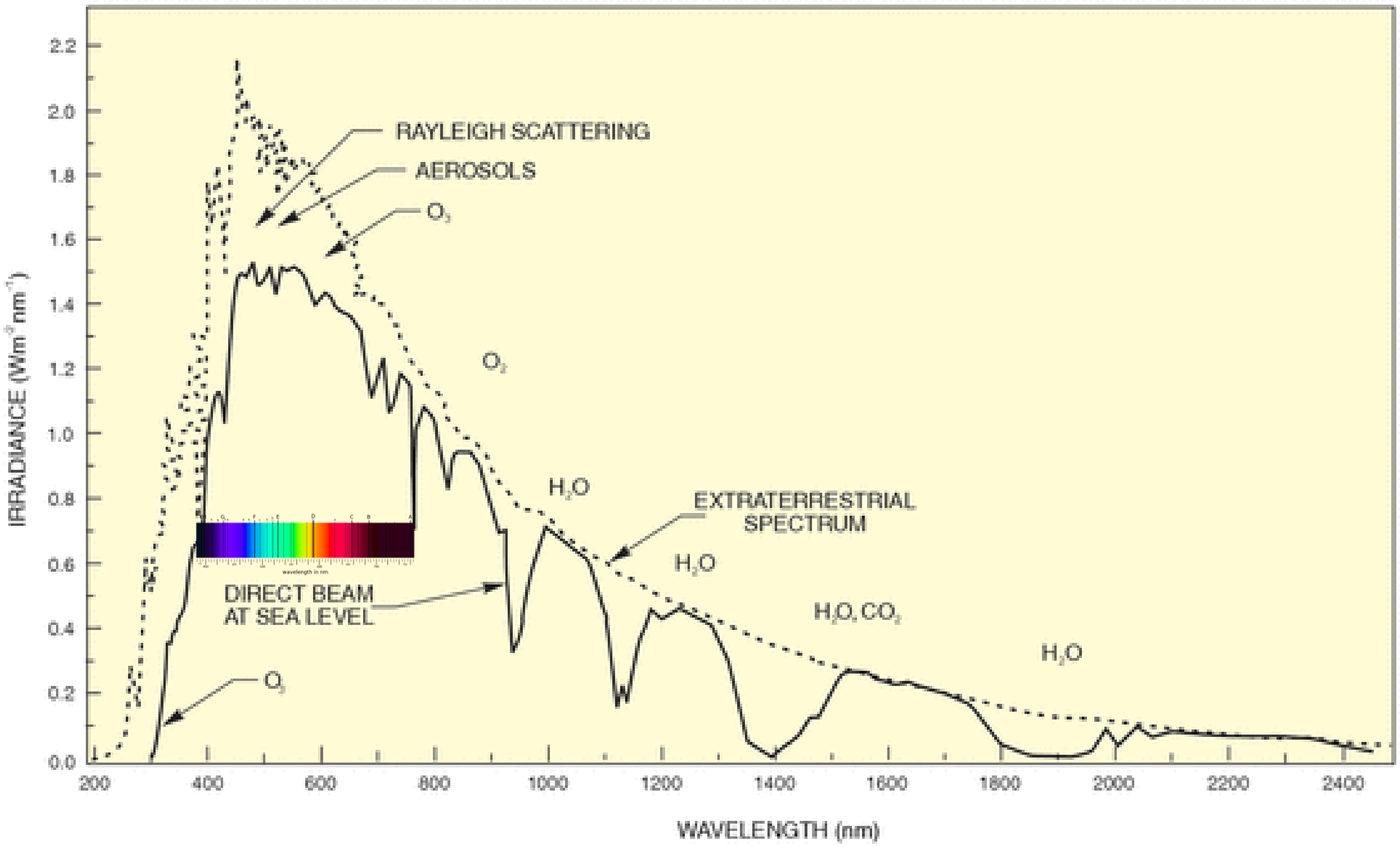
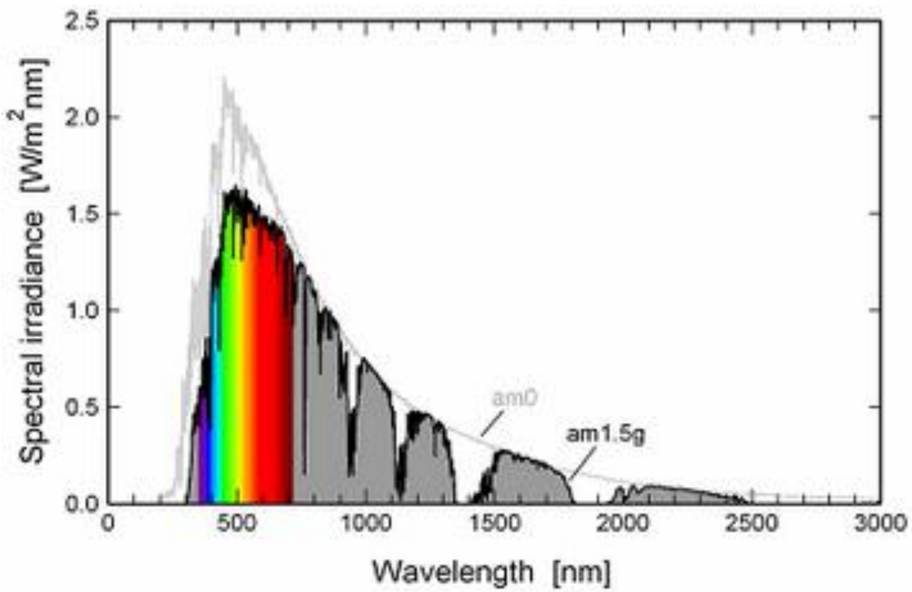
# Solar Spectra

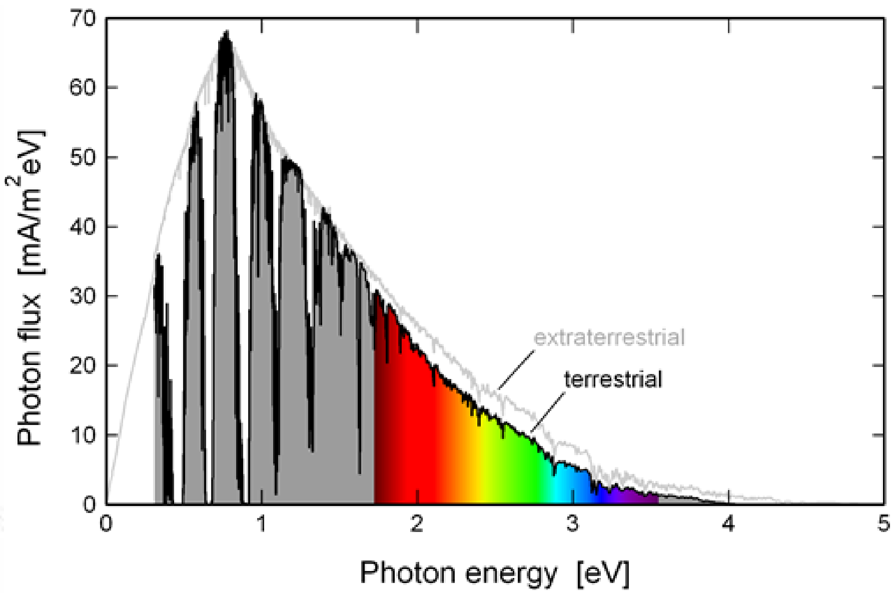



http://www.stellarnet.us/popularconfigurations_radiosystems_solar.htm

# Spectral Irradiance and Photon Flux

Spectral irradiance (left) and photon flux (right) of the AM1.5g spectrum




$$Watt = \frac{Joule}{s}$$

$$\lambda(nm) = \frac{1240}{E_g(eV)}$$

$$1\,eV = 1.6\times10^{-19}\,Joule$$

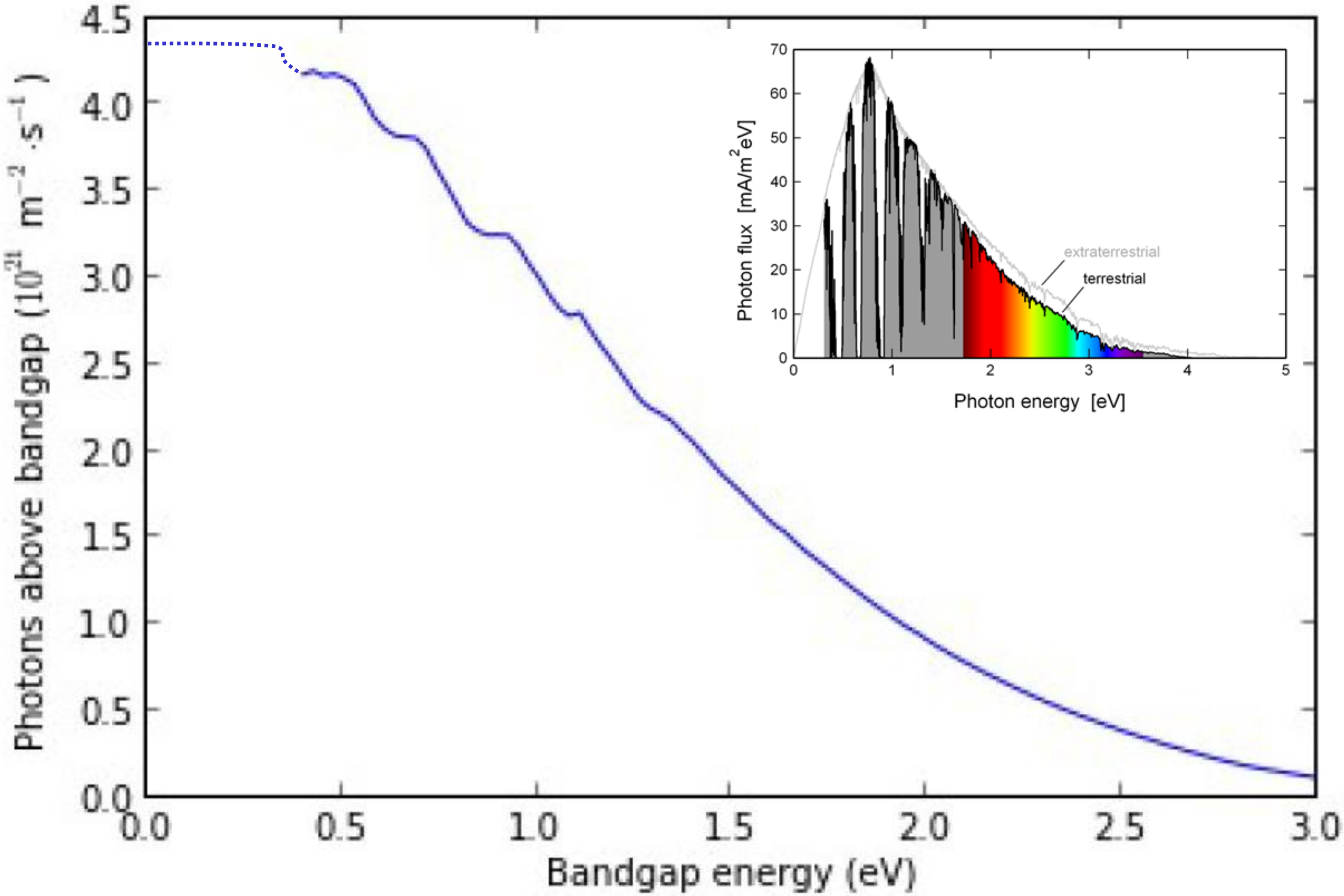
$$\#electron = \frac{Photon\ energy\ (Joule)}{1.6\times10^{-19}\ joule\,/\,electron}$$

$$Coul = (\#electron)\times1.6\times10^{-19}\,Coul\,/\,electron$$

$$Amp = \frac{Coul}{s}$$

http://www.pvlighthouse.com.au/resources/courses/altermatt/The%20Solar%20Spectrum/The%20global%20standard%20spectrum%20(AM1-5g).aspx

# Photon above Bandgap




Assumes photons above the bandgap is 100% absorbed, and below is 0%.

http://sjbyrnes.com/?page_id=15

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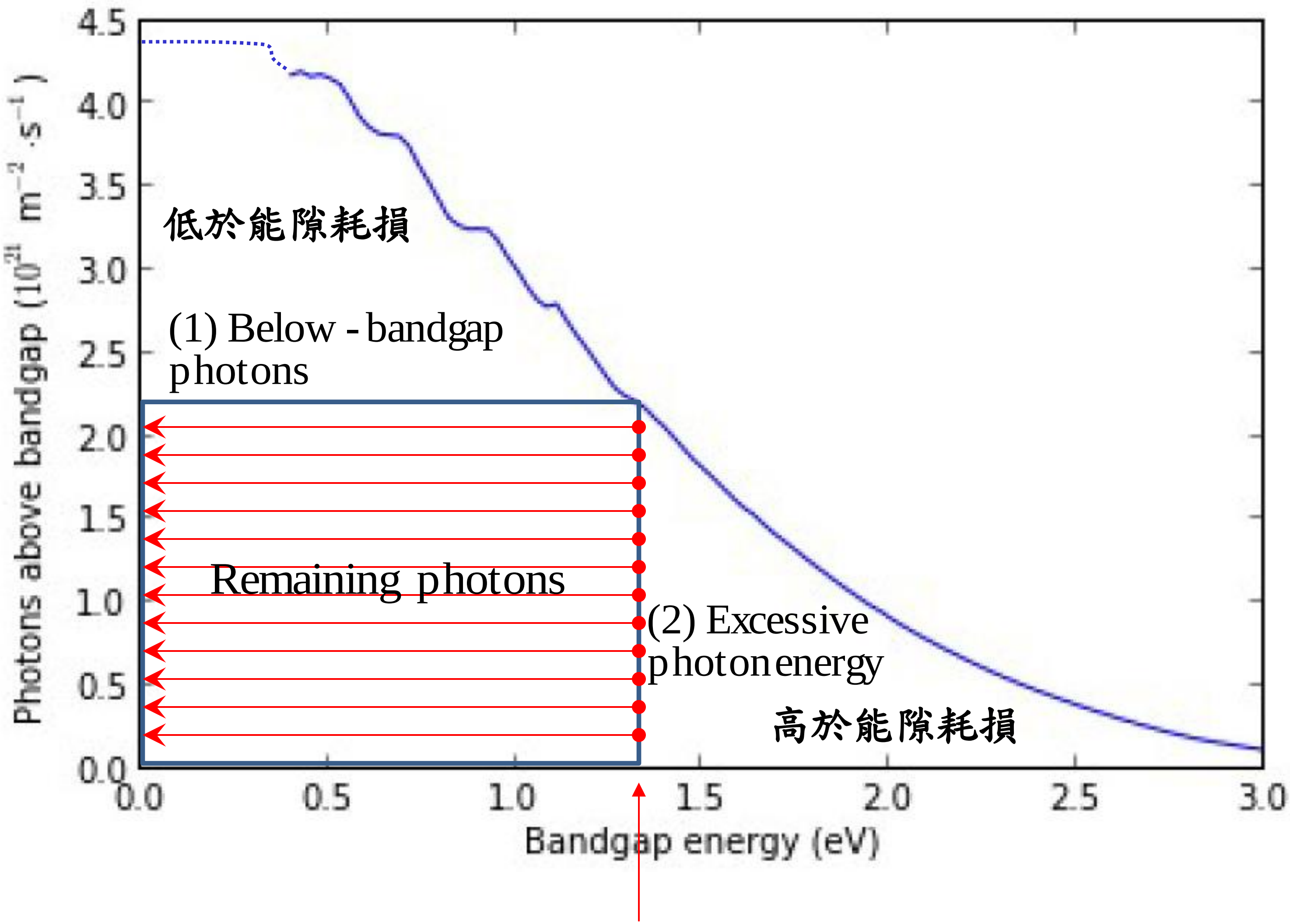
# Loss Mechanisms

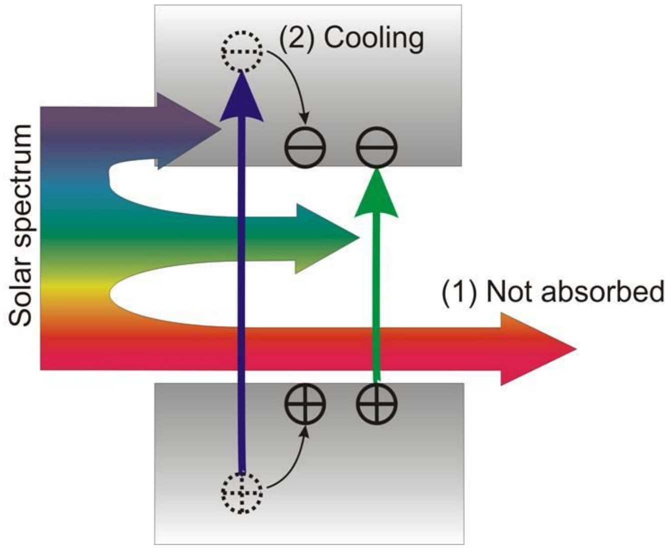
1. Transmission loss
2. Thermalization loss
3. Radiative recombination loss
4. Fill factor loss
5. (Other losses)

# Two Major Loss Mechanisms




Assumes a single p-n junction diode solar cell with bandgap equaling 1.34 eV.

# Transmission and Thermalization Losses




**(1) 低於能隙耗損**

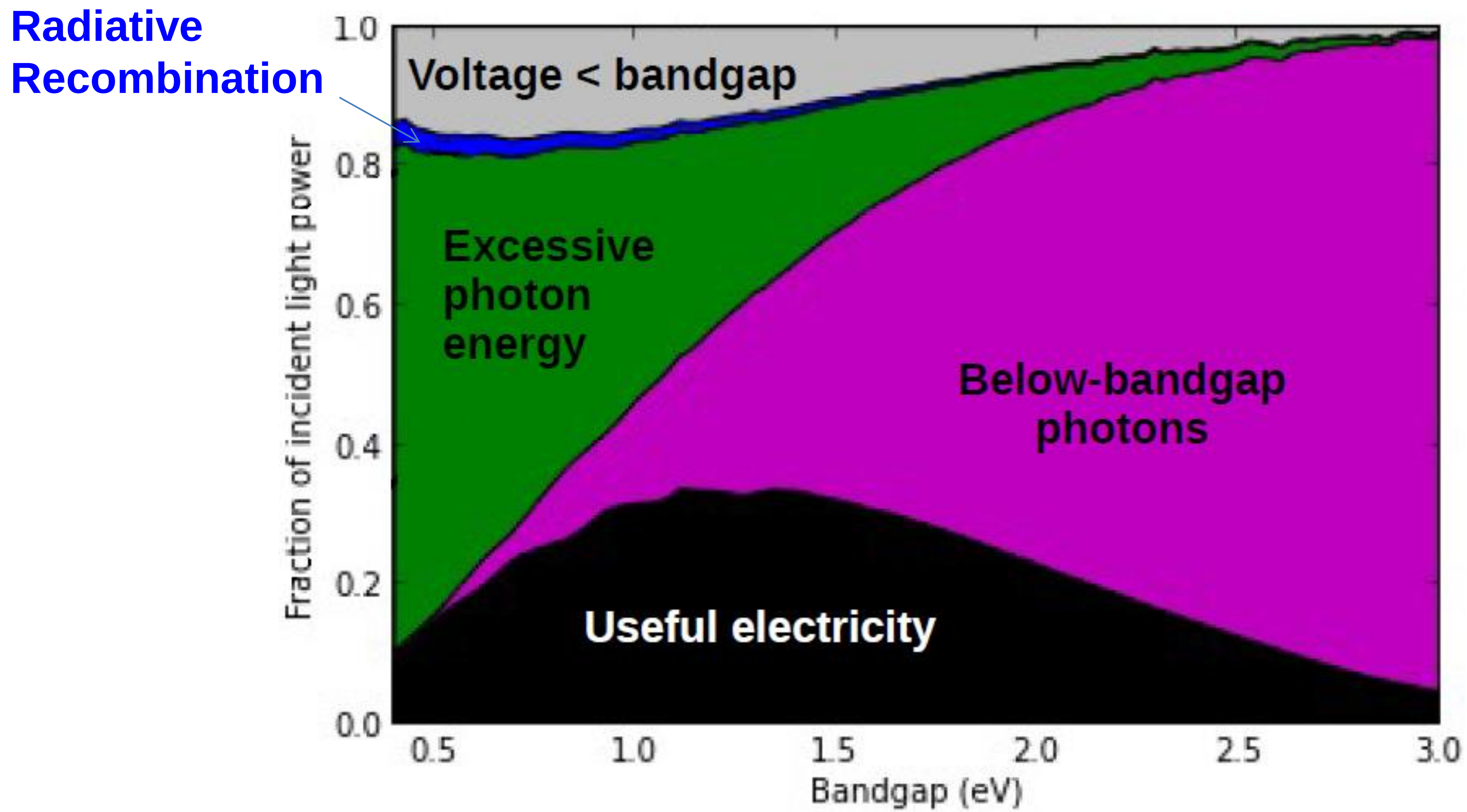
- Transmission loss
- Below bandgap photon loss

**(2) 高於能隙耗損**

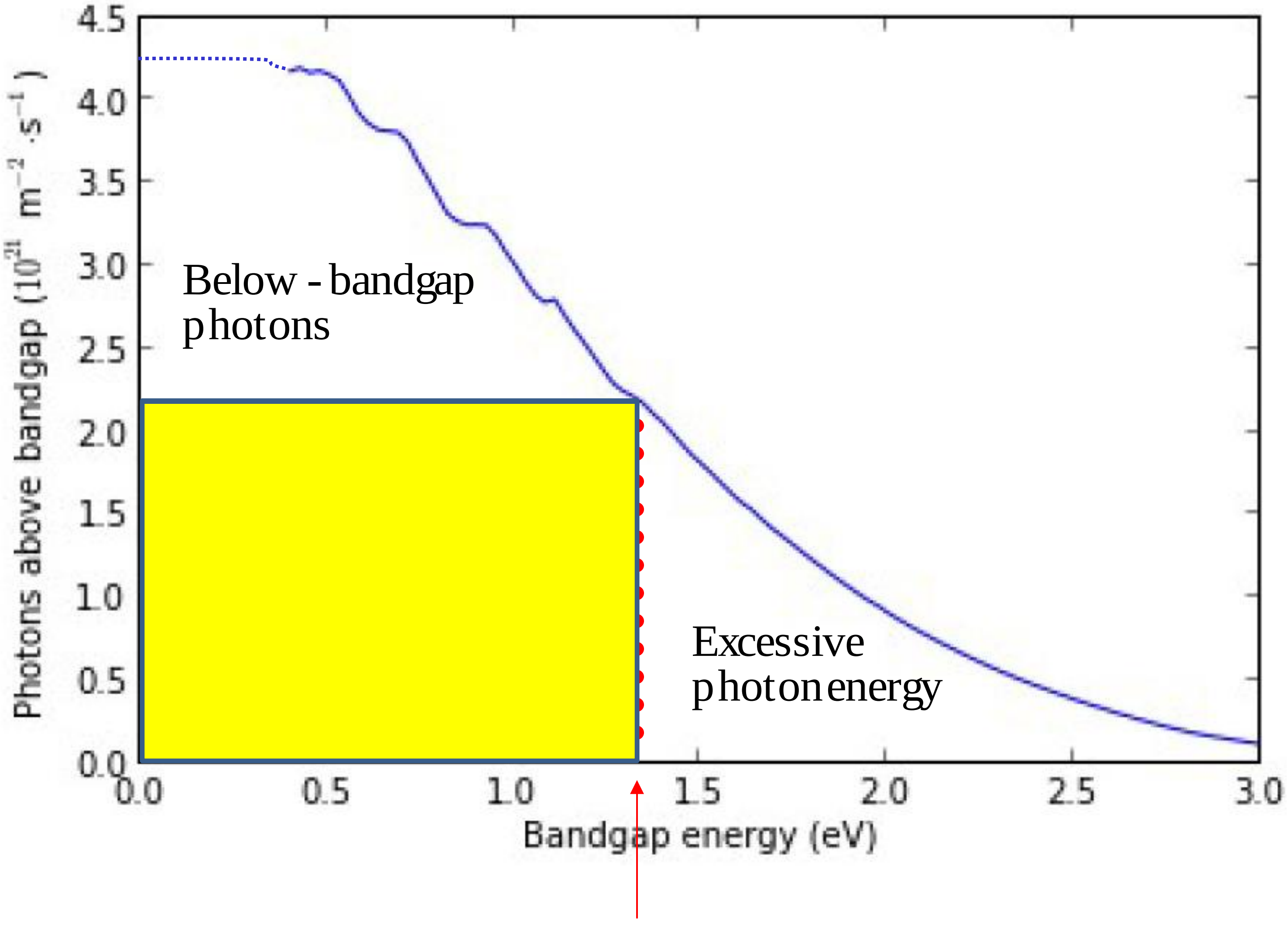
- Thermalization loss
- Excessive photon energy loss
- Cooling loss

http://www2.mpip-mainz.mpg.de/~canovas/research.htm

# Power Breakdown



# For Single Junction Structure

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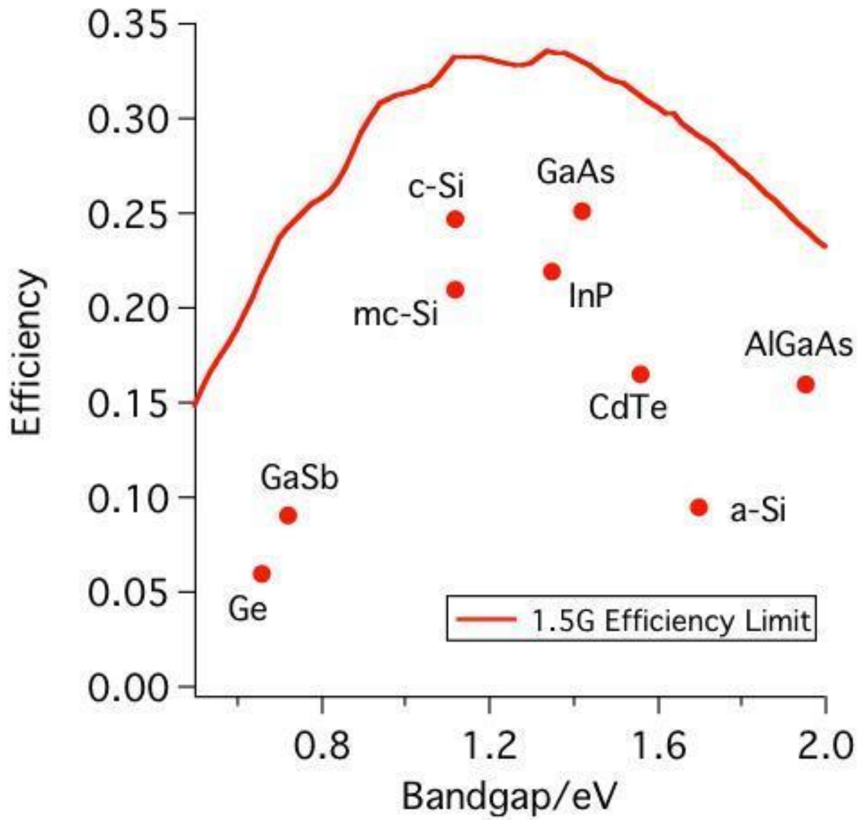


http://solarjourneyusa.com/bandgaps.php

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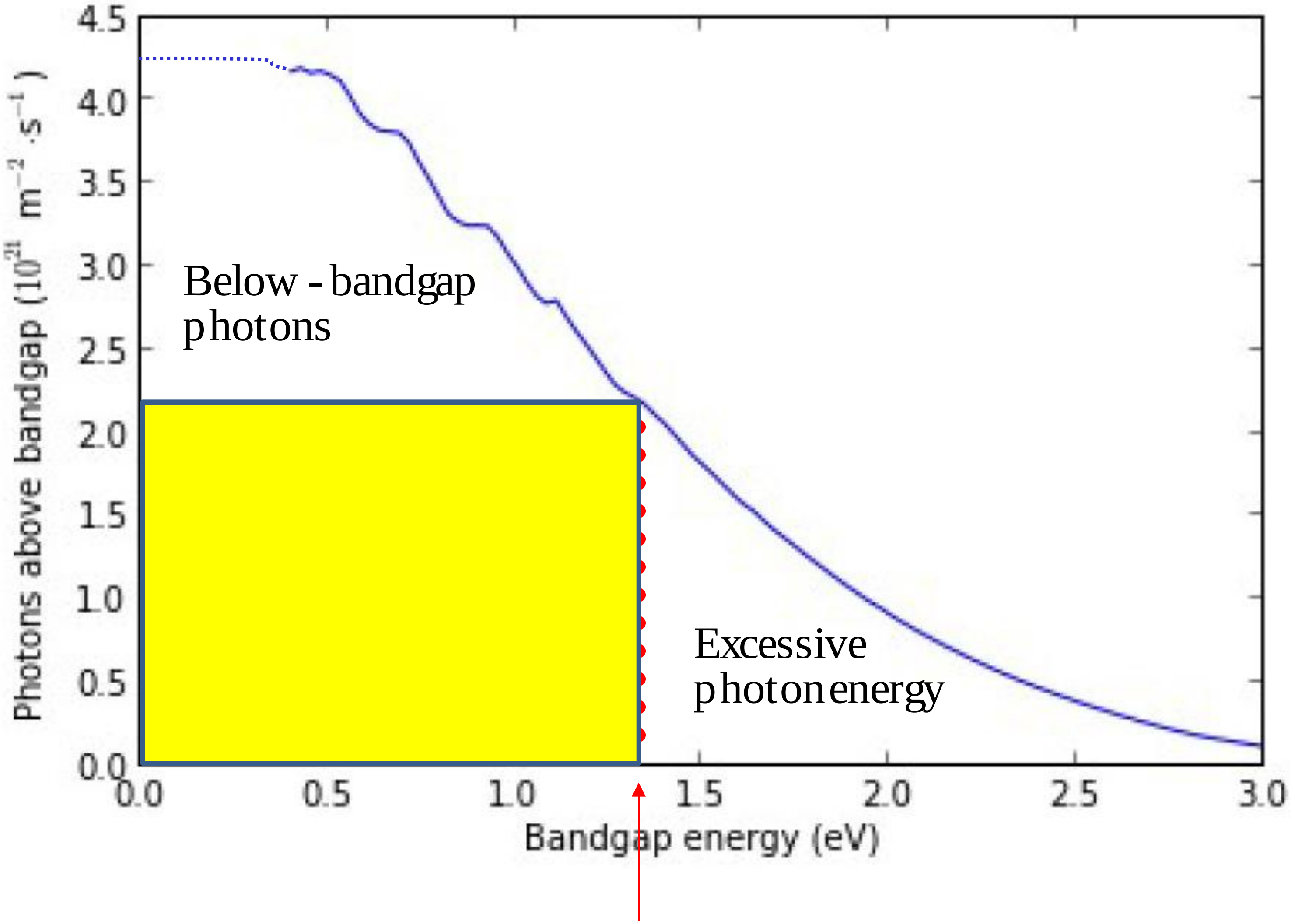
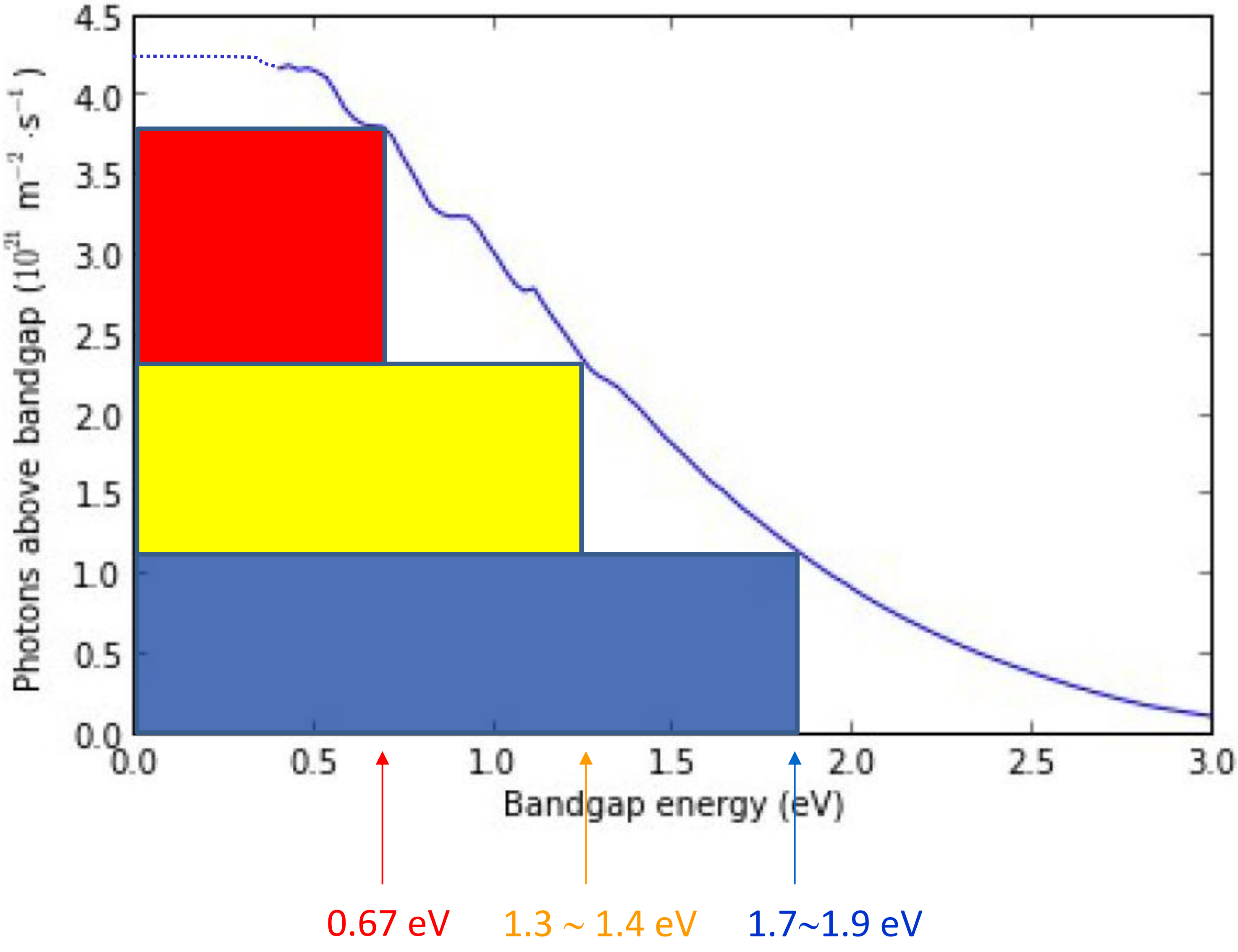
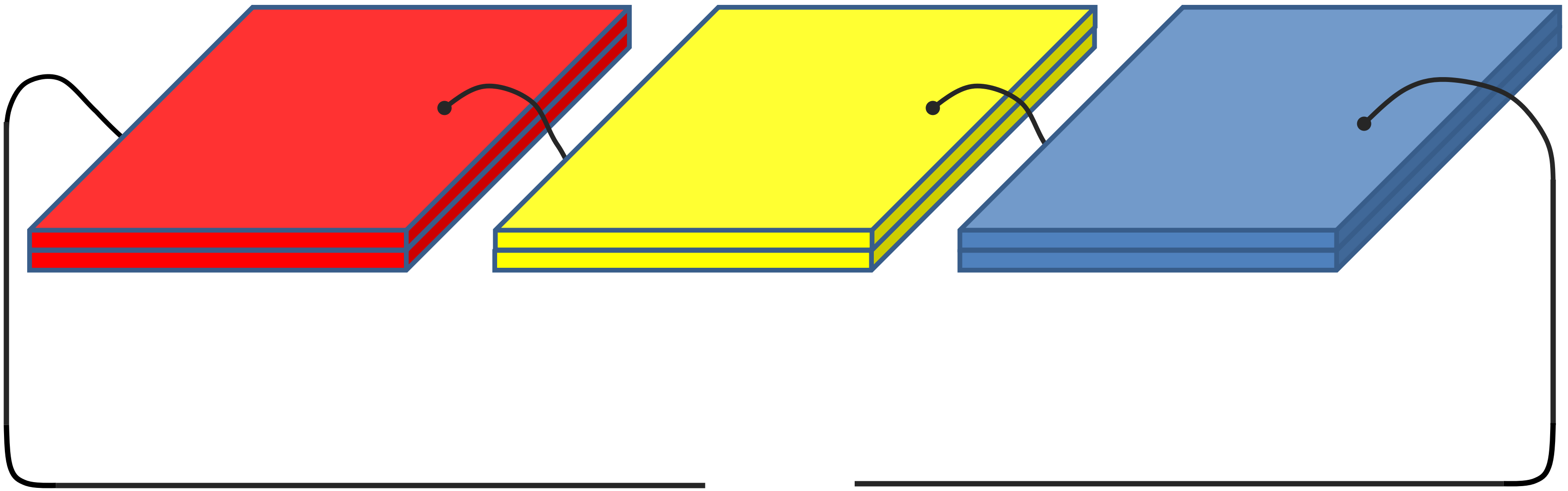



Assumes a single p-n junction diode solar cell with bandgap equaling 1.34 eV.

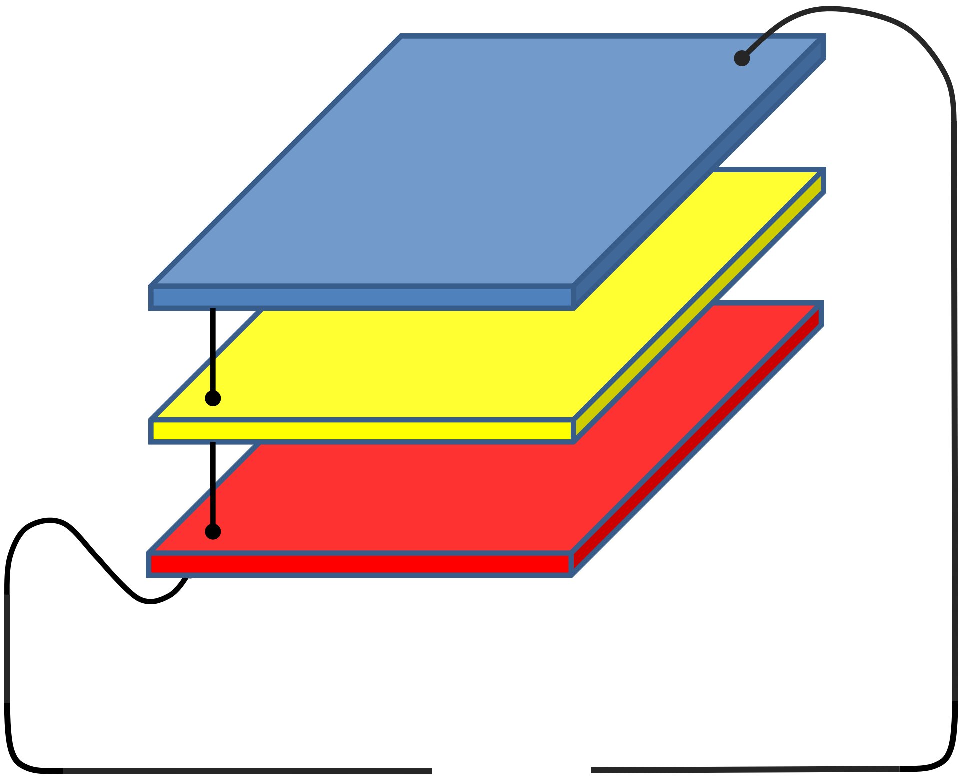
# Separate Cells



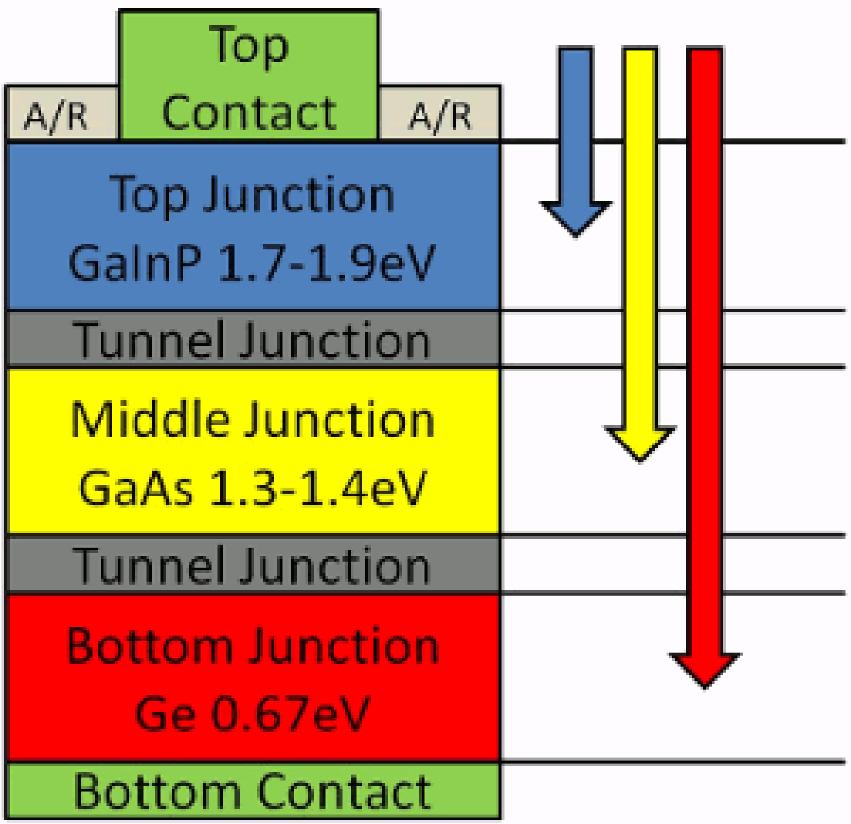
# Separate Cell Arrangement



# For Tandem Structure



# For Tandem Structure




http://large.stanford.edu/courses/2010/ph240/weisse2/

# Tandem Structure Initiatives and requirements

**Initiatives**

1. Multiple cells responsible for absorbing different sectors of spectrum.
2. Multiple cells but occupying the same cell area.

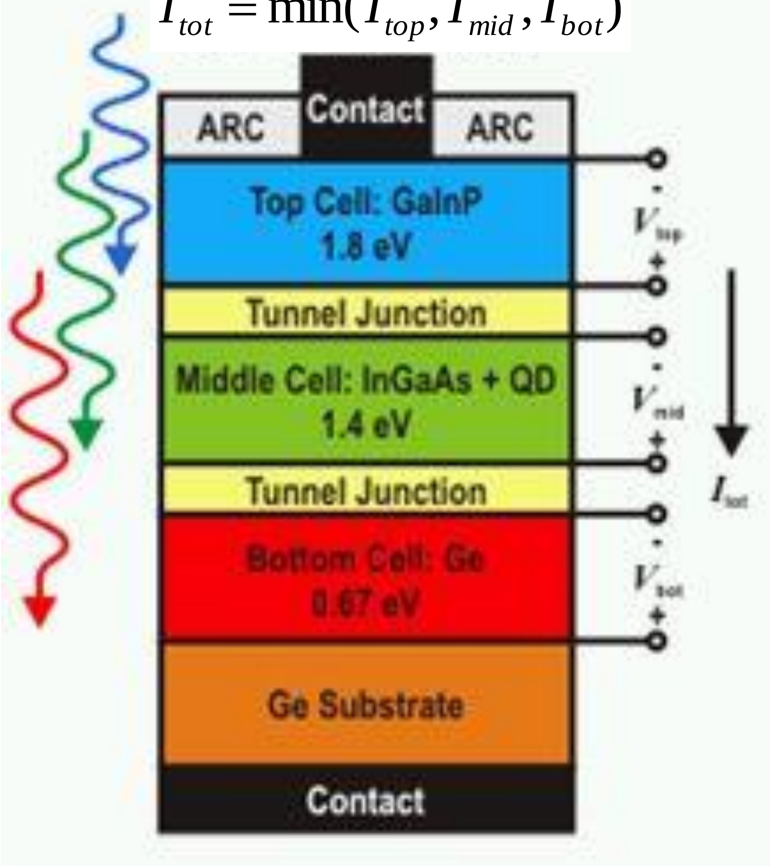
**Requirements**

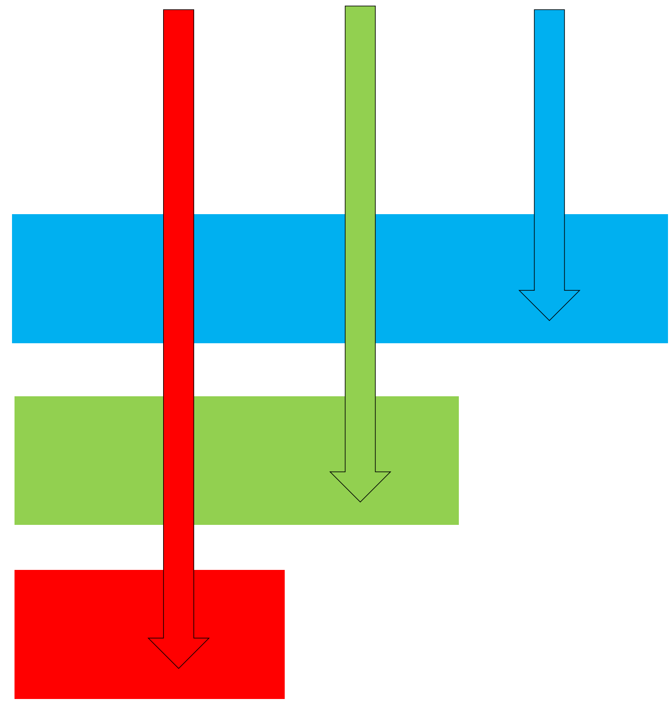
1. Require transparency of the upper layers for the light to be absorbed by the lower layers.
2. Require transparent series connection between consecutive cells.

# Current Constraint

$$V_{tot} = V_{top} + V_{mid} + V_{bot}$$

$$I_{tot} = \min(I_{top}, I_{mid}, I_{bot})$$

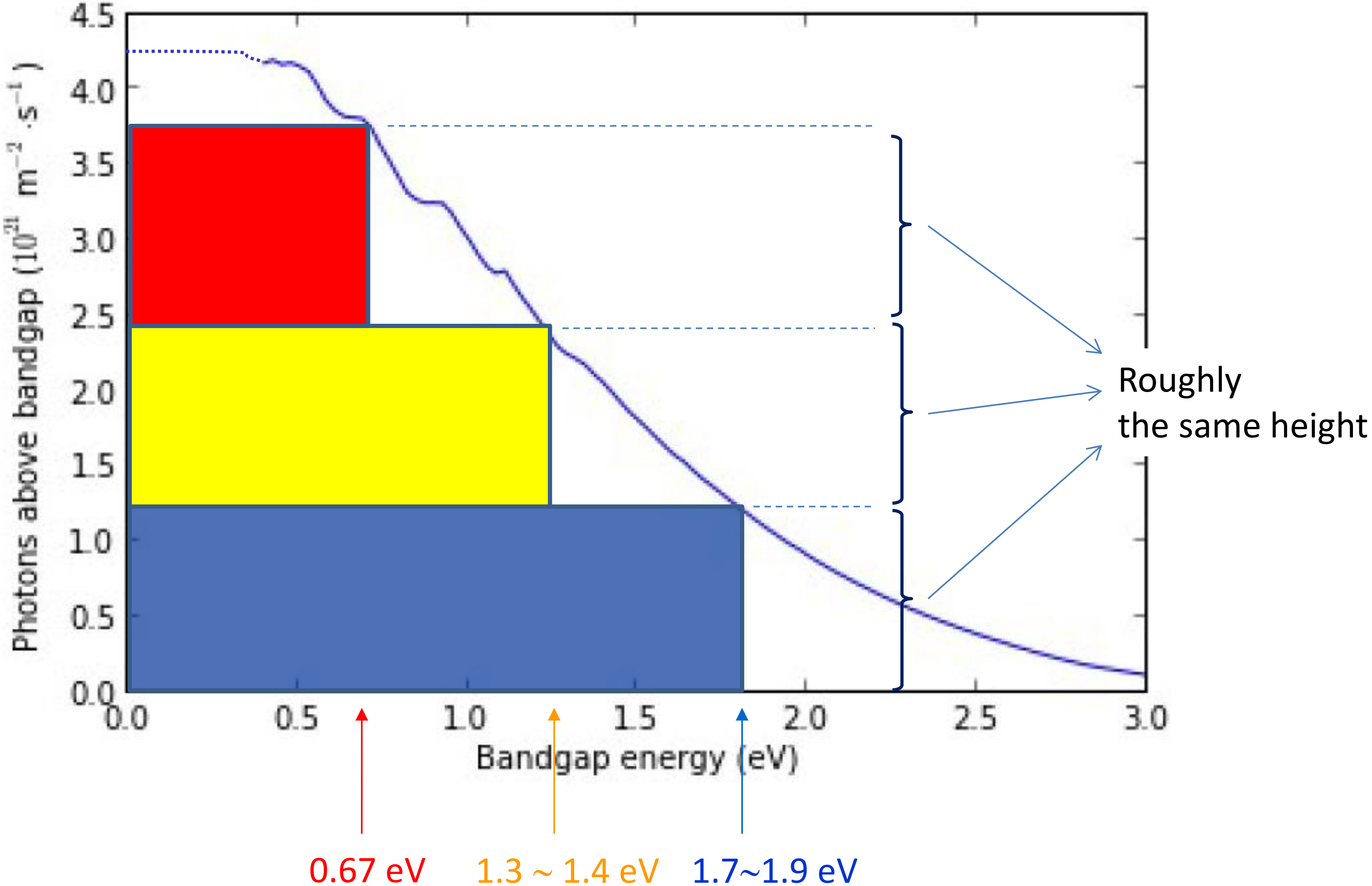


Source: Sunlab, Canada

http://re.energybel.by/en/solar-energy-overview/#!prettyPhoto

# Bandgap Selection for Current Constraint



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# Nominal Thicknesses of the Dual-Junction Solar Cell

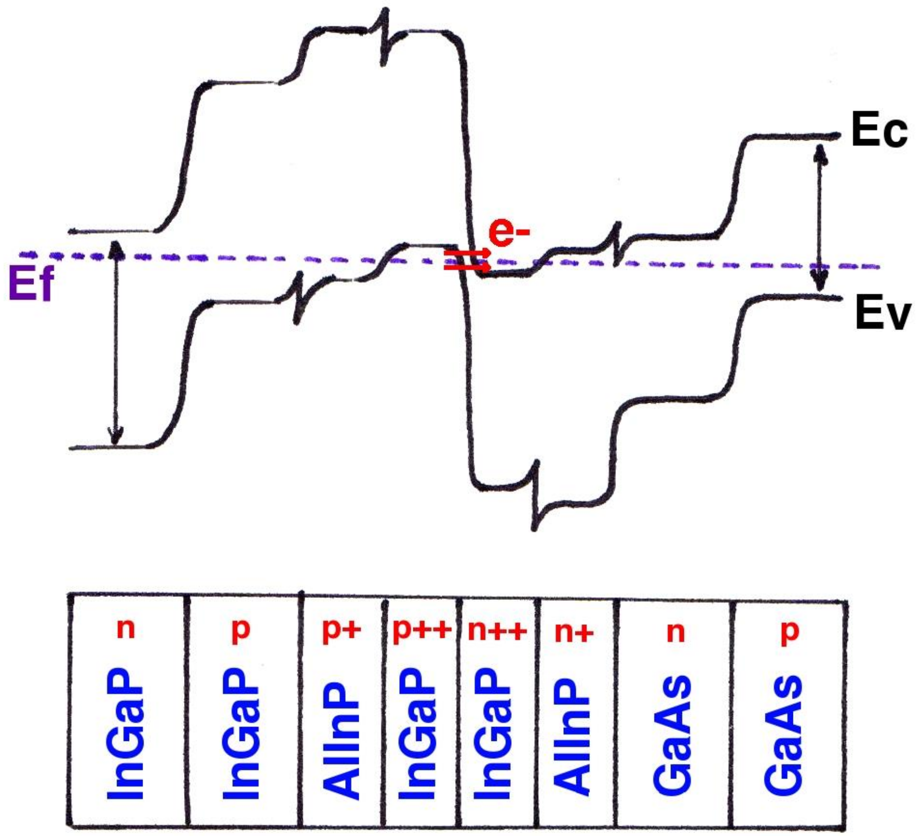
| Name | Material | Thickness | N [cm$^{-3}$] |
|---|---|---|---|
| topfsf | AlInP | 50 nm | n = 3.0 $10^{+17}$ |
| topem | $Ga_{0.51}In_{0.49}P$ | 170 nm | n = 1.8 $10^{+18}$ |
| topbase | $Ga_{0.51}In_{0.49}P$ | 800 nm | p = 1.0 $10^{+17}$ |
| topbsf | AlGaInP | 100 nm | p = 3.0 $10^{+17}$ |
| phighTD | GaAs | 50 nm | p = 5.0 $10^{+19}$ |
| nhighTD | GaAs | 50 nm | n = 3.0 $10^{+19}$ |
| botfsf | $Al_{0.4}Ga_{0.6}As$ | 50 nm | n = 2.0 $10^{+18}$ |
| botem | GaAs | 100 nm | n = 1.0 $10^{+10}$ |
| botbase | GaAs | 3500 nm | p = 2.0 $10^{+17}$ |
| botbsf | $Al_{0.3}Ga_{0.7}As$ | 100 nm | p = 2.0 $10^{+18}$ |
| subs | GaAs | 300 µm | p = 2.0 $10^{+18}$ |

back surface field (BSF)

http://www.silvaco.com/tech_lib_TCAD/simulationstandard/2009/jan_feb_mar/a1/a1.html

# Tunnel Junction

Metal interconnect is not adequate for the tandem cells. **Why?**






http://en.wikipedia.org/wiki/Multijunction_photovoltaic_cell

# Tunnel Junction for Interconnect

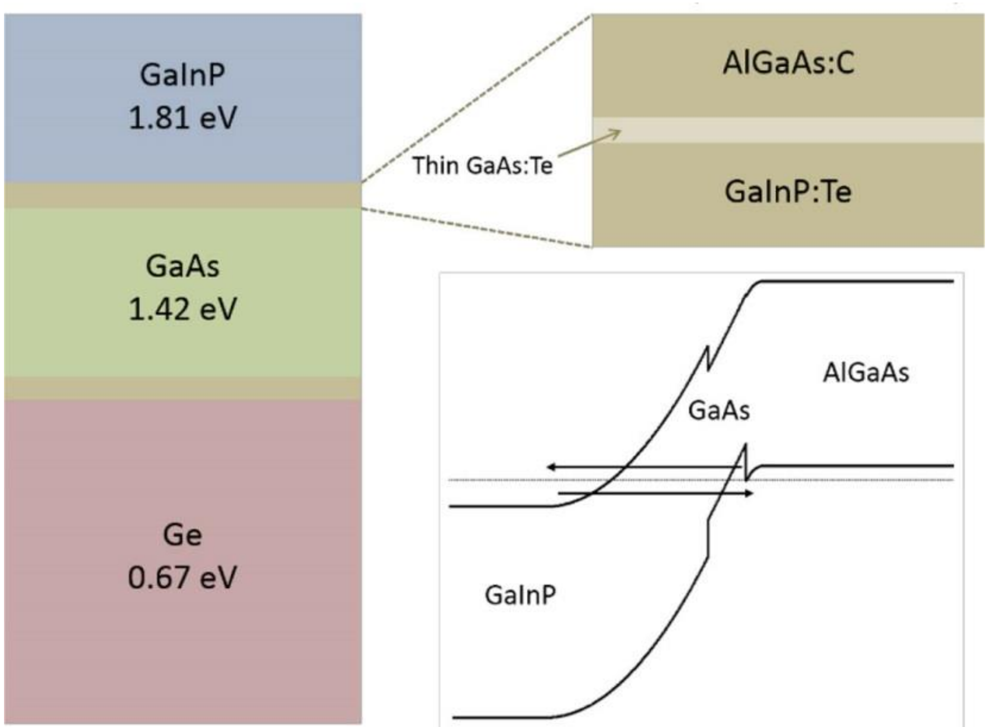
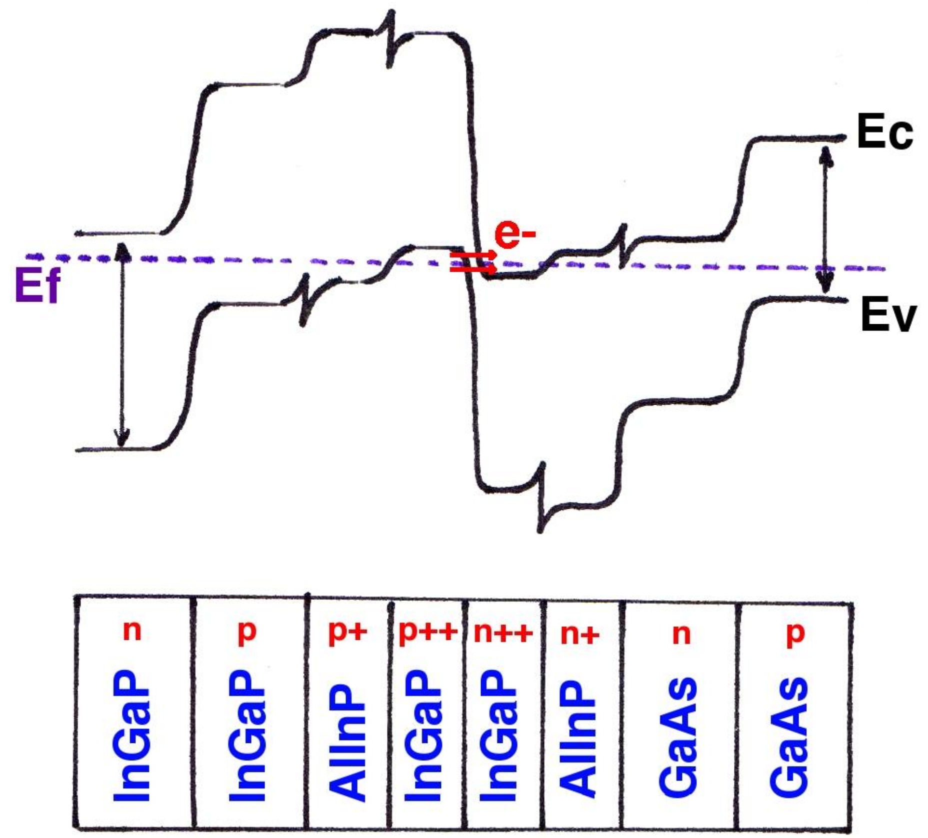



**Figure 1.** Location of the new tunnel junction (TJ) structure in a multijunction (MJ) solar cell. Also shown is the band diagram for a TJ with a 30Å gallium arsenide (GaAs) layer. GaInP: Gallium indium phosphide. Ge: Germanium. AlGaAs:C: Carbon-doped aluminum gallium arsenide. GaAs:Te: Tellurium-doped GaAs. GaInP:Te: Tellurium-doped GaInP.

http://spie.org/x105129.xml

# Tunnel Junction



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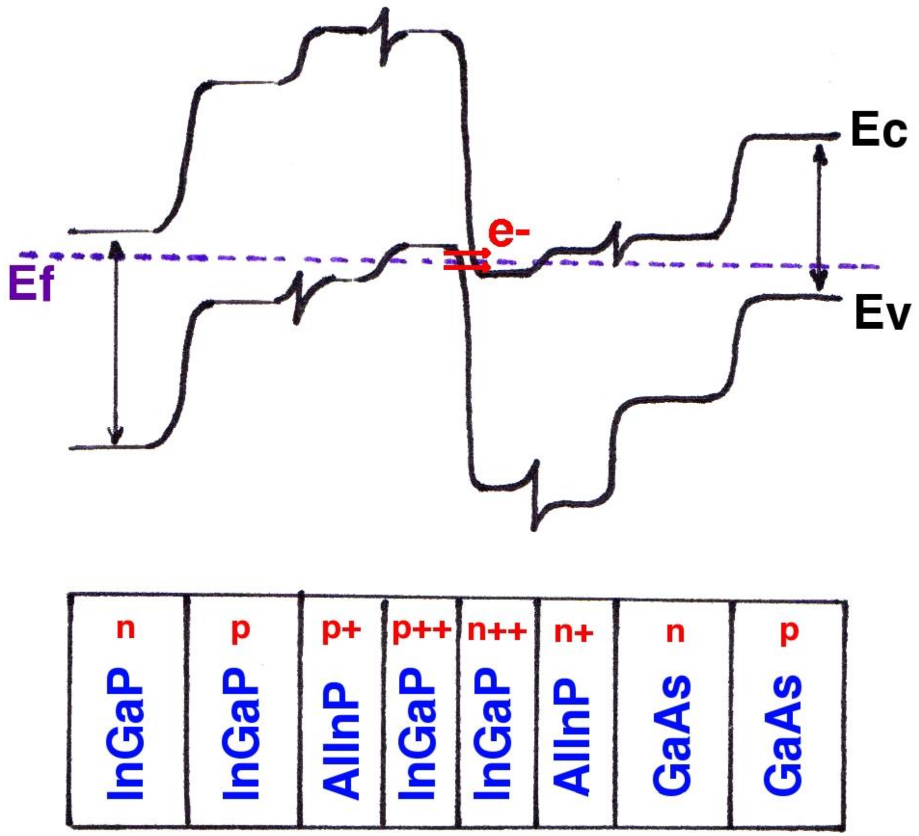
# Tunnel Junction with Back Surface Field Design






http://en.wikipedia.org/wiki/Multijunction_photovoltaic_cell

# Back Surface Field (BSF)

A back-surface field (BSF) layer reduces the scattering of carriers towards the tunnel junction.

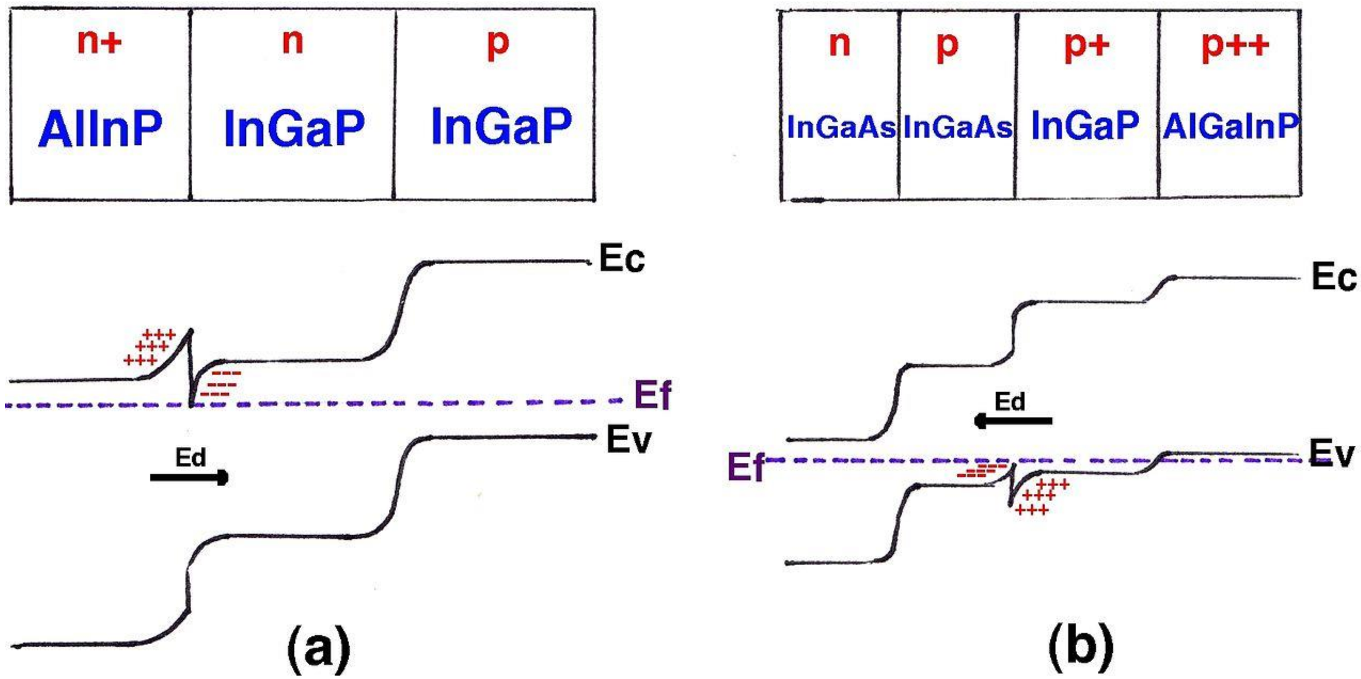
Employed at the rear surface to minimize the impact of rear surface recombination velocity on voltage and current if the rear surface is closer than a diffusion length to the junction.

A "back surface field" (BSF) consists of a higher doped region at the rear surface of the solar cell. The interface between the high and low doped region behaves like a p-n junction and an electric field forms at the interface which introduces a barrier to minority carrier flow to the rear surface. The minority carrier concentration is thus maintained at higher levels in the bulk of the device and the BSF has a net effect of passivating the rear surface.

Fossum JG. Physical operation of back-surface-field silicon solar cells. IEEE Transactions on Electron Devices. 1977 ;24:322 - 325.

http://www.pveducation.org/pvcdrom/design/surface-recombination

# Window and BSF Layers




(a) Layers and band diagram of a window layer. The surface recombination is reduced.
(b) Layers and band diagram of a BSF layer. The scattering of carriers is reduced.

http://en.wikipedia.org/wiki/Multijunction_photovoltaic_cell

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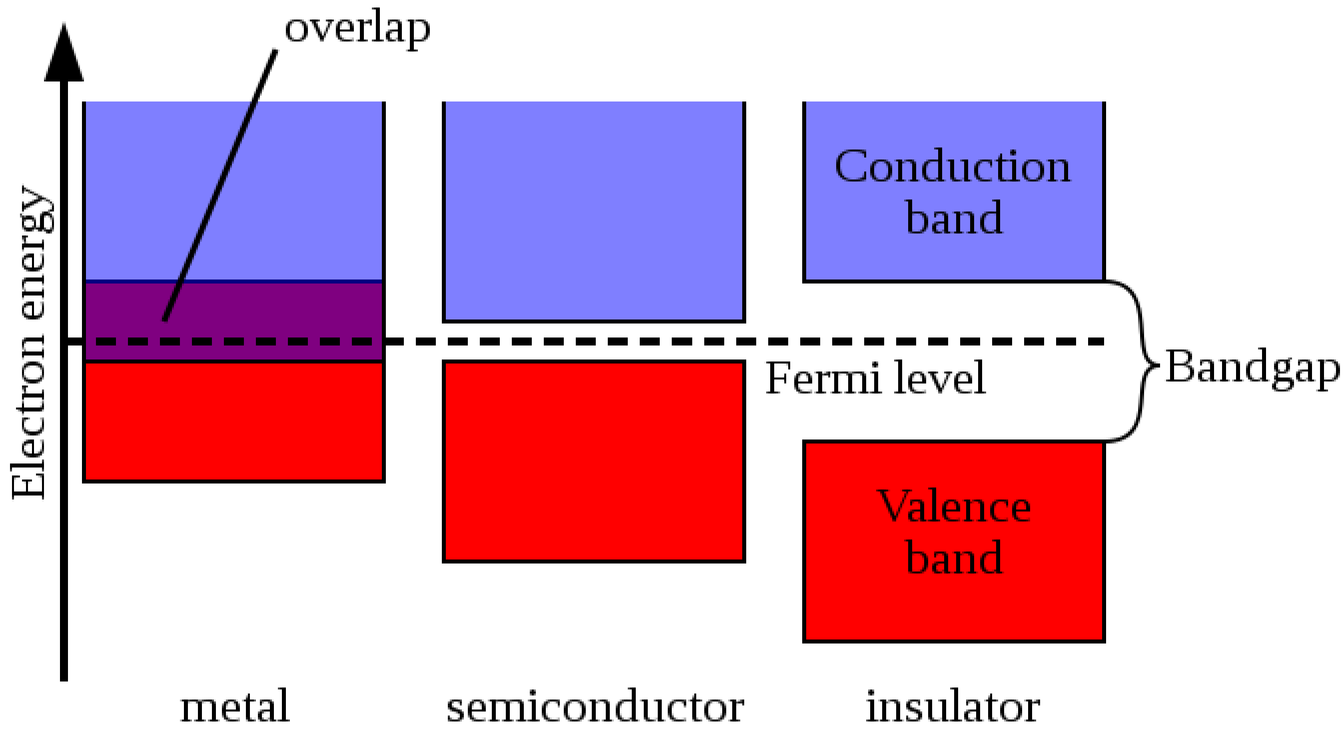
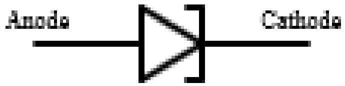
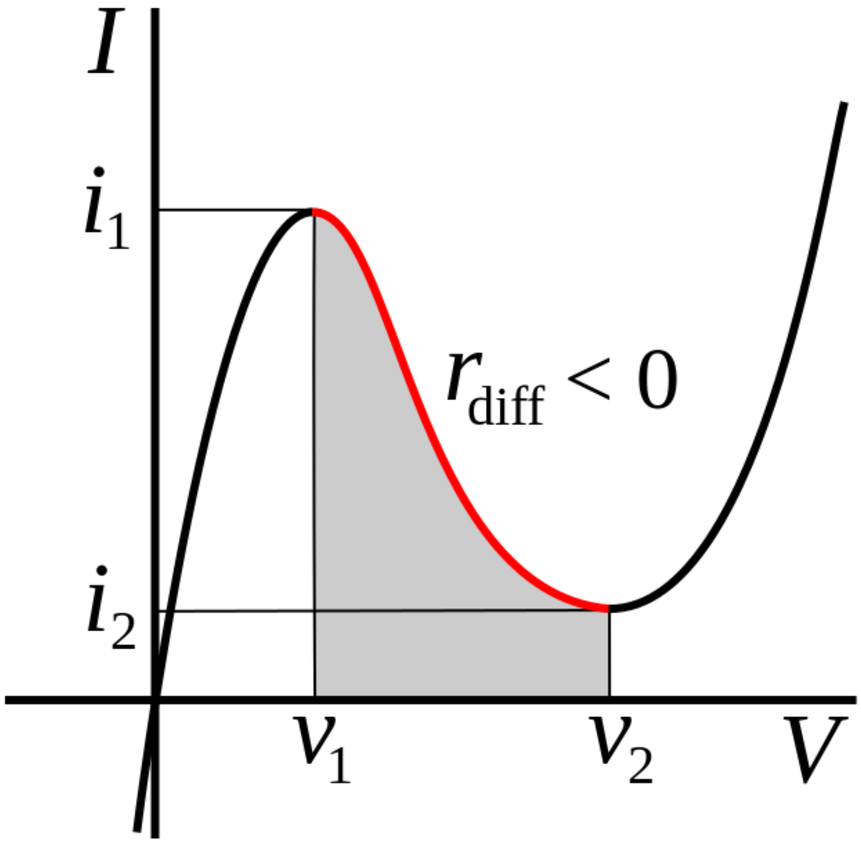



http://vovprcj.blogspot.tw/2013_01_09_archive.html

# Tunnel Diode




"Voltage controlled negative resistance" by Chetvorno - Own work. Licensed under CC0 via Wikimedia Commons - http://commons.wikimedia.org/wiki/File:Voltage_controlled_negative_resistance.svg#/media/File:Voltage_controlled_negative_resistance.svg

http://en.wikipedia.org/wiki/Tunnel_diode

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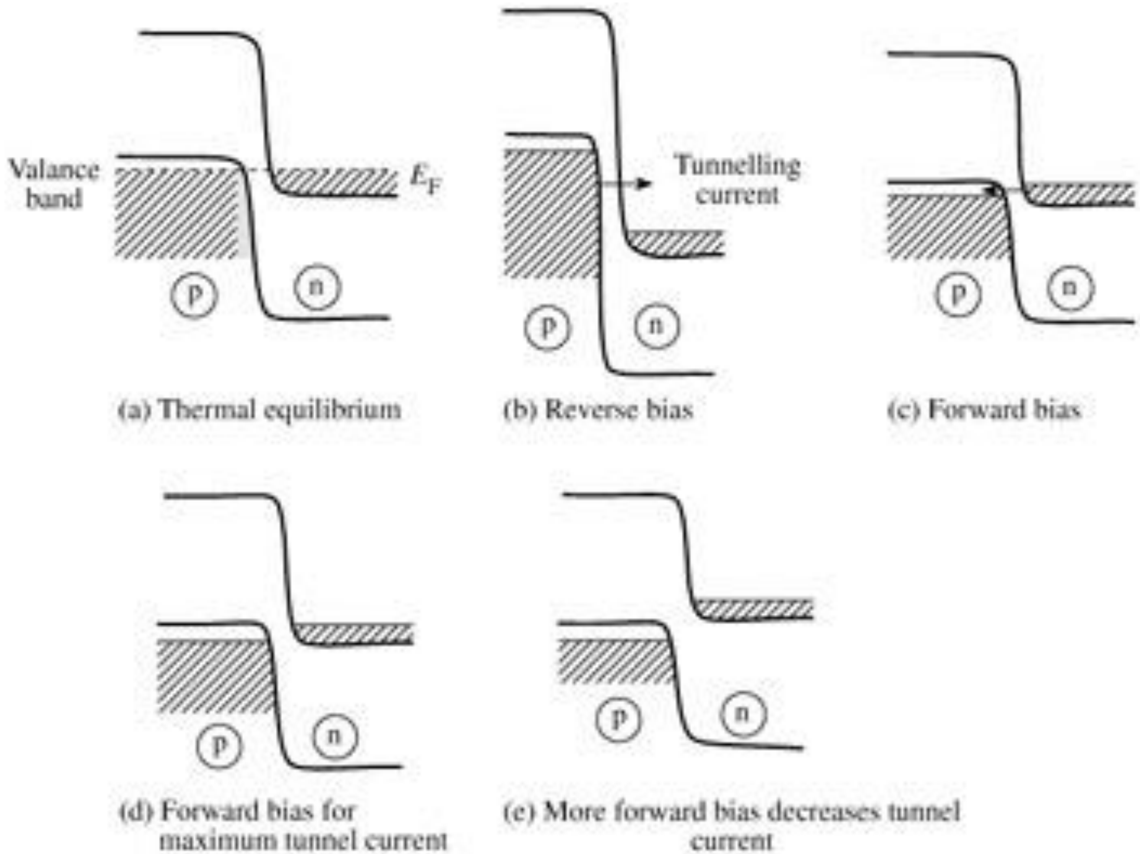
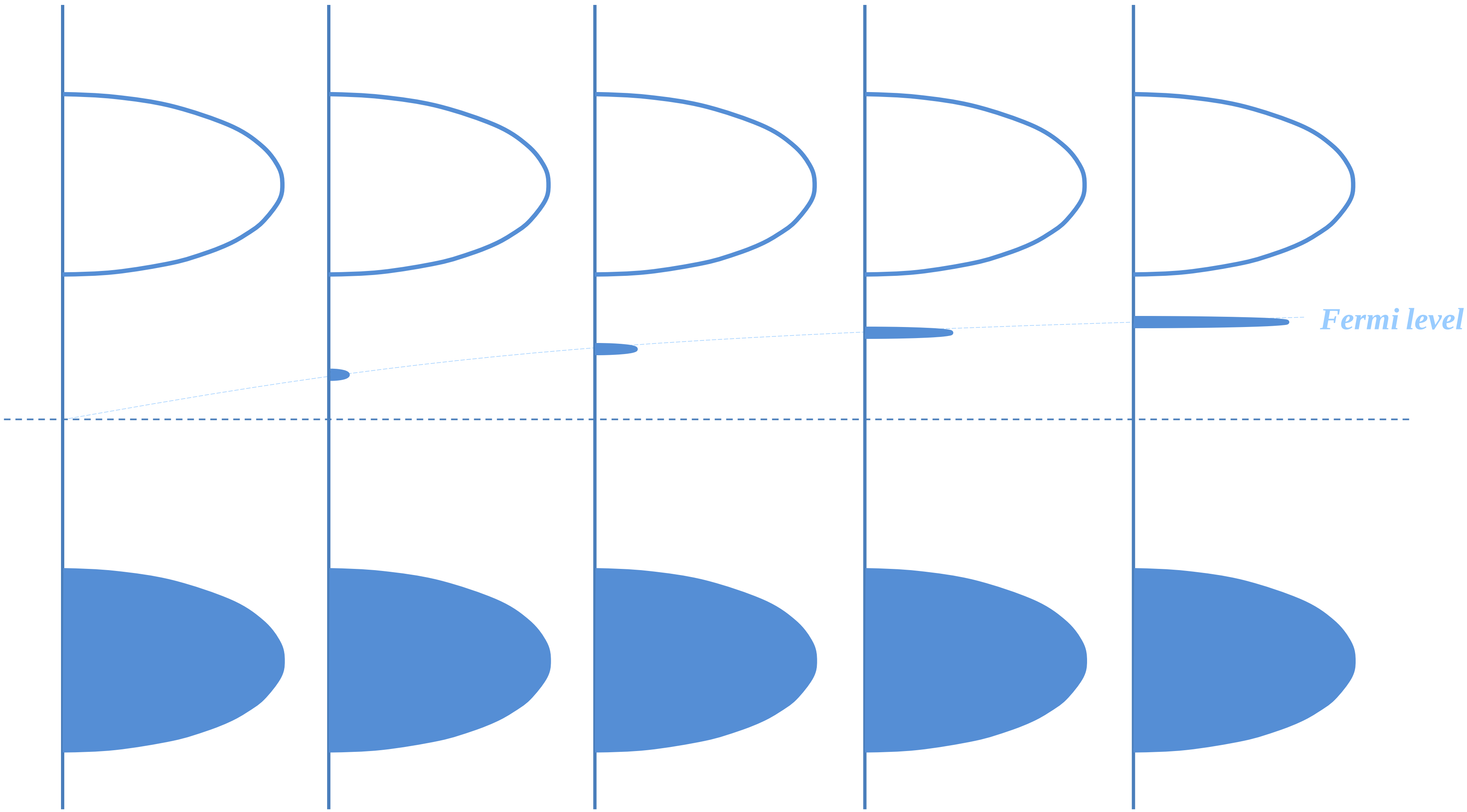



http://www.globalspec.com/reference/59802/203279/9-10-the-tunnel-diode

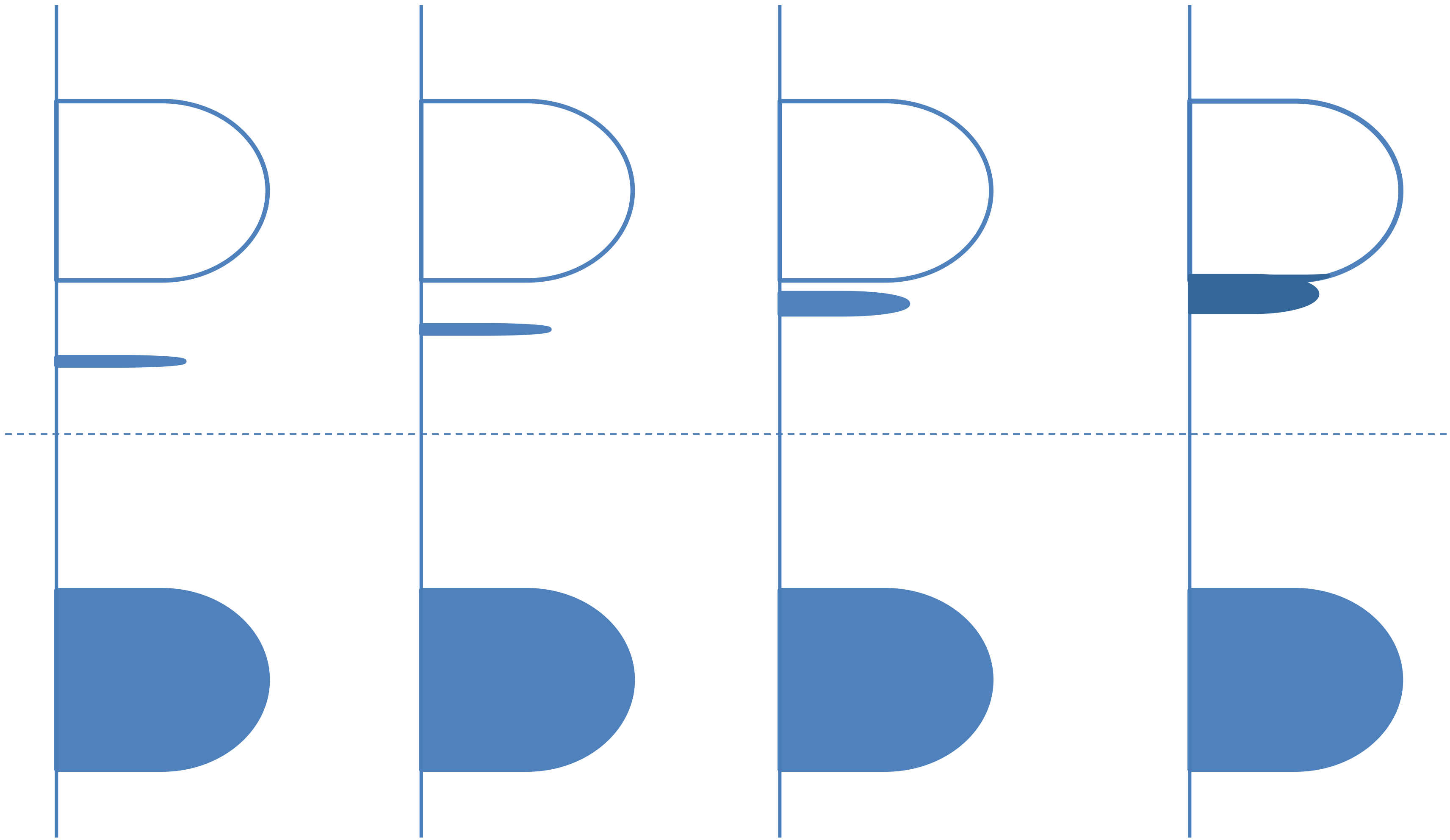
# Fermi Level Change with Doping Concentration




Intrinsic

**Increasing doping concentration**

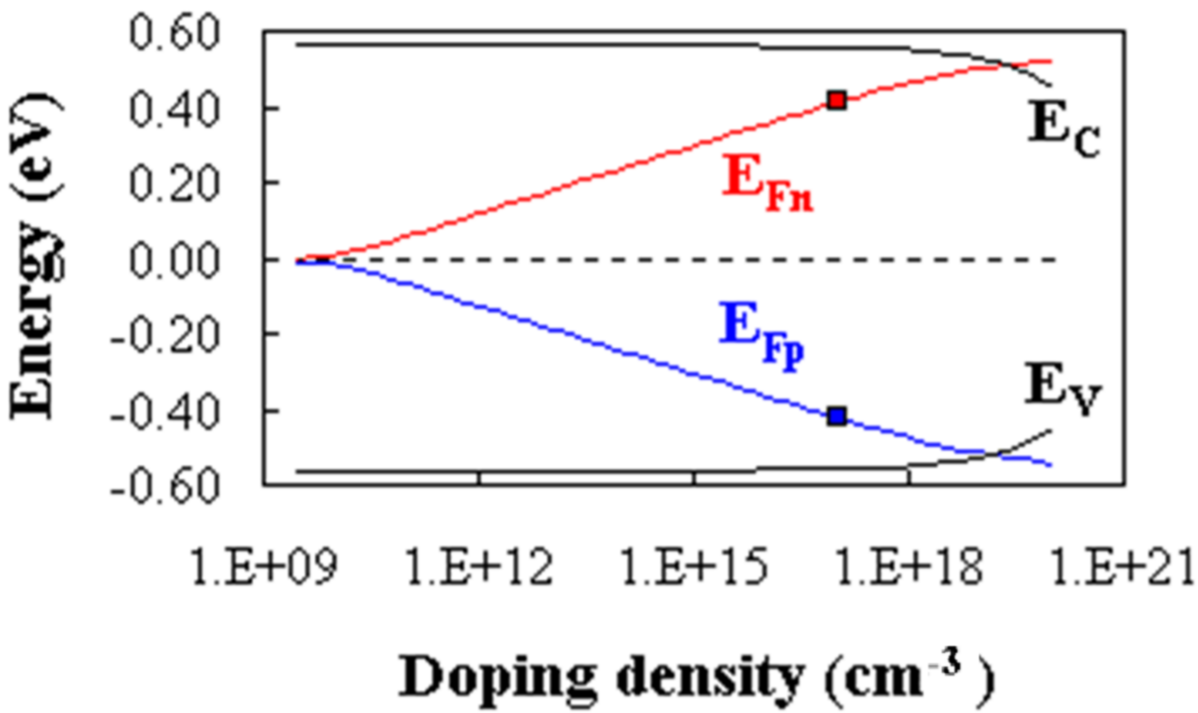
# Degenerate Semiconductor



# Fermi Level and Doping Density

$$E_F = E_i + kT \ln \frac{n}{n_i}$$

$$E_F = E_i - kT \ln \frac{p}{n_i}$$




http://ecee.colorado.edu/~bart/book/extrinsi.htm

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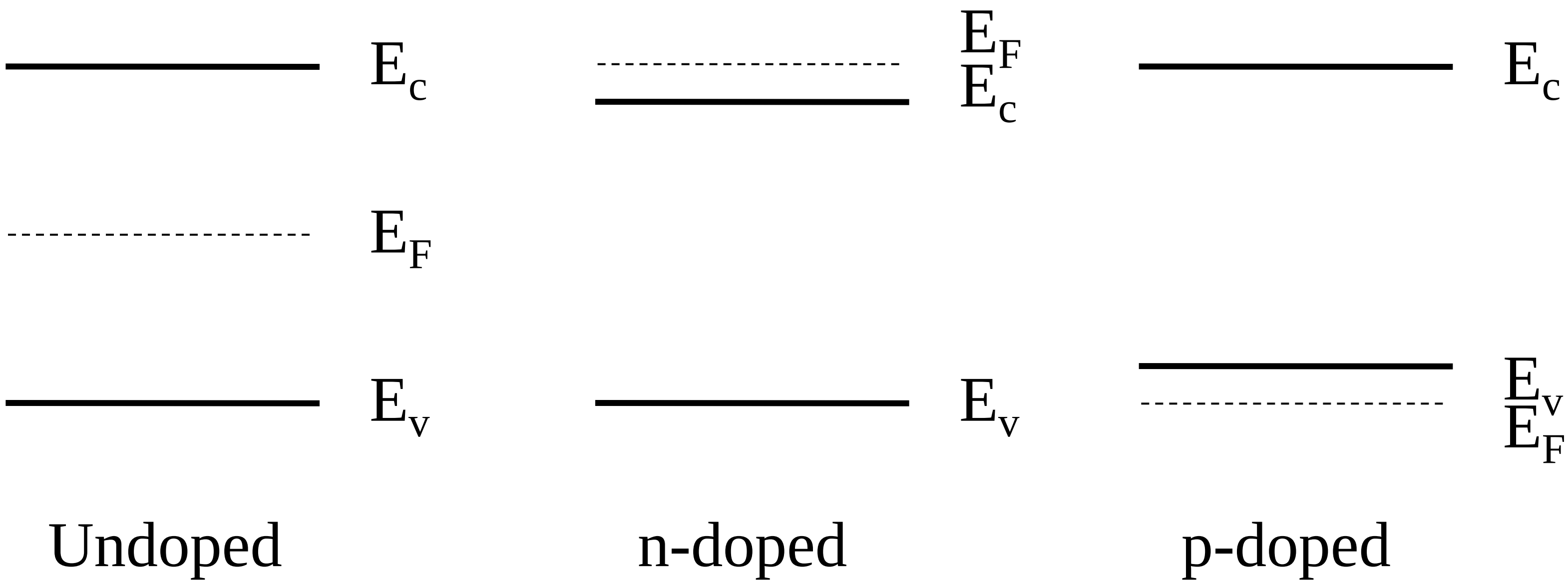
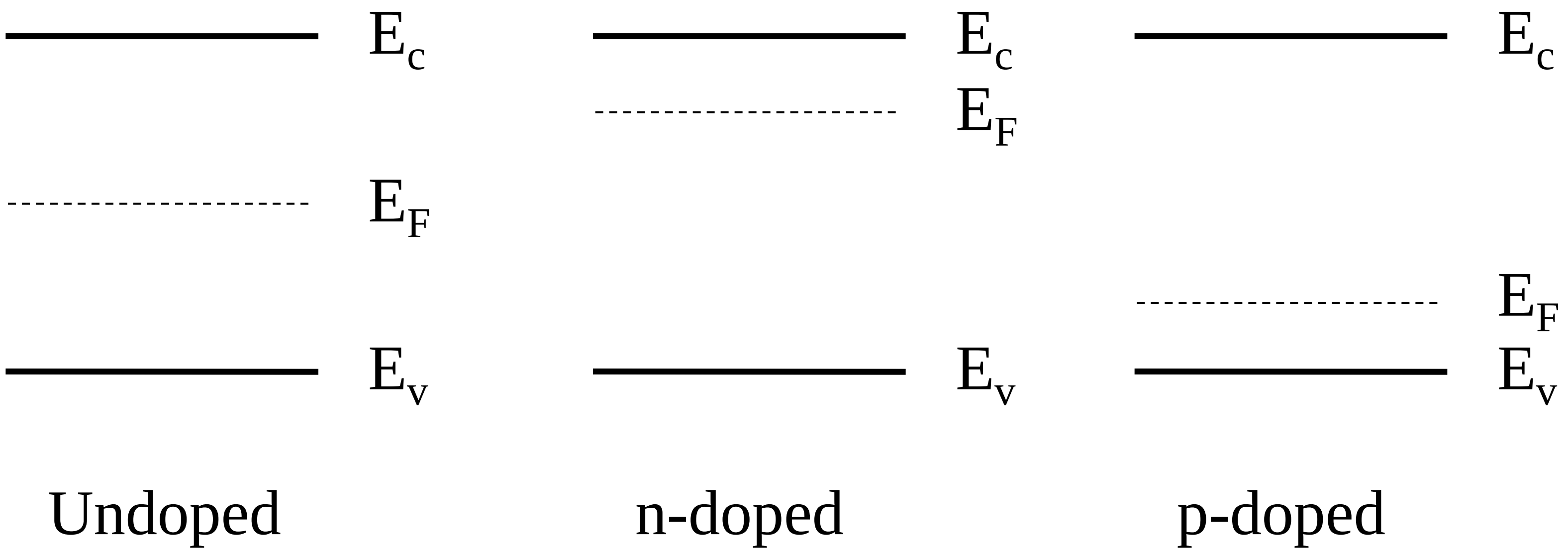



$E_F$ : Fermi level (where electron occupation probability is 50%)

# Doping of a Semiconductor




$E_F$ : Fermi level (where electron occupation probability is 50%)

The location of Fermi level changes with doping type. ***Why?***

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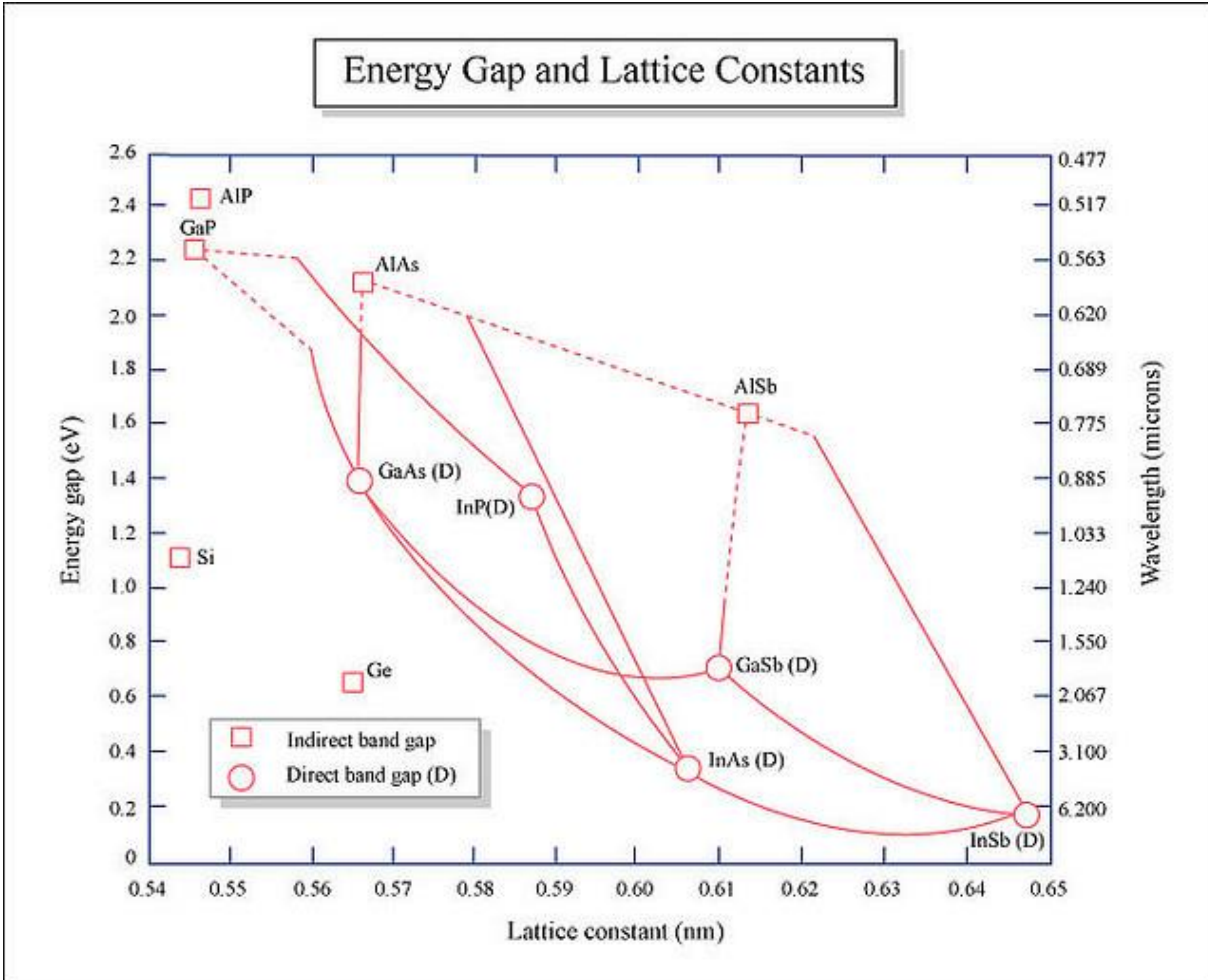
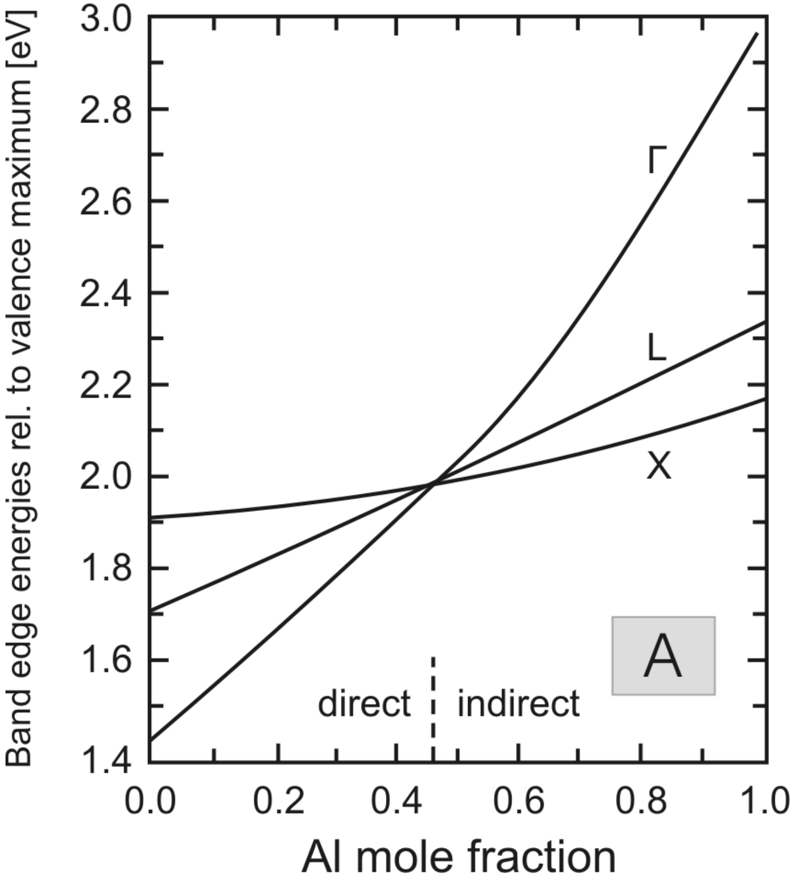
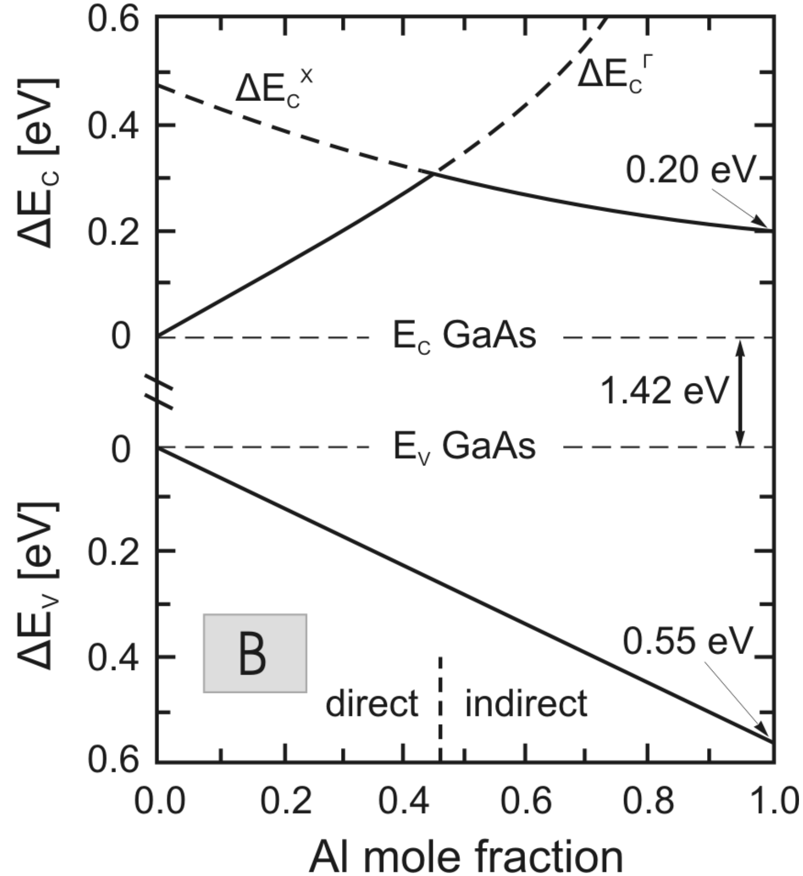


Energy Gap and Lattice Constants
Energy gap (eV)
Wavelength (microns)
Lattice constant (nm)
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
0.477
0.517
0.563
0.620
0.689
0.775
0.885
1.033
1.240
1.550
2.067
3.100
6.200
0.54
0.55
0.56
0.57
0.58
0.59
0.60
0.61
0.62
0.63
0.64
0.65
AlP
GaP
AlAs
AlSb
GaAs (D)
InP(D)
Si
Ge
GaSb (D)
InAs (D)
InSb (D)
Indirect band gap
Direct band gap (D)

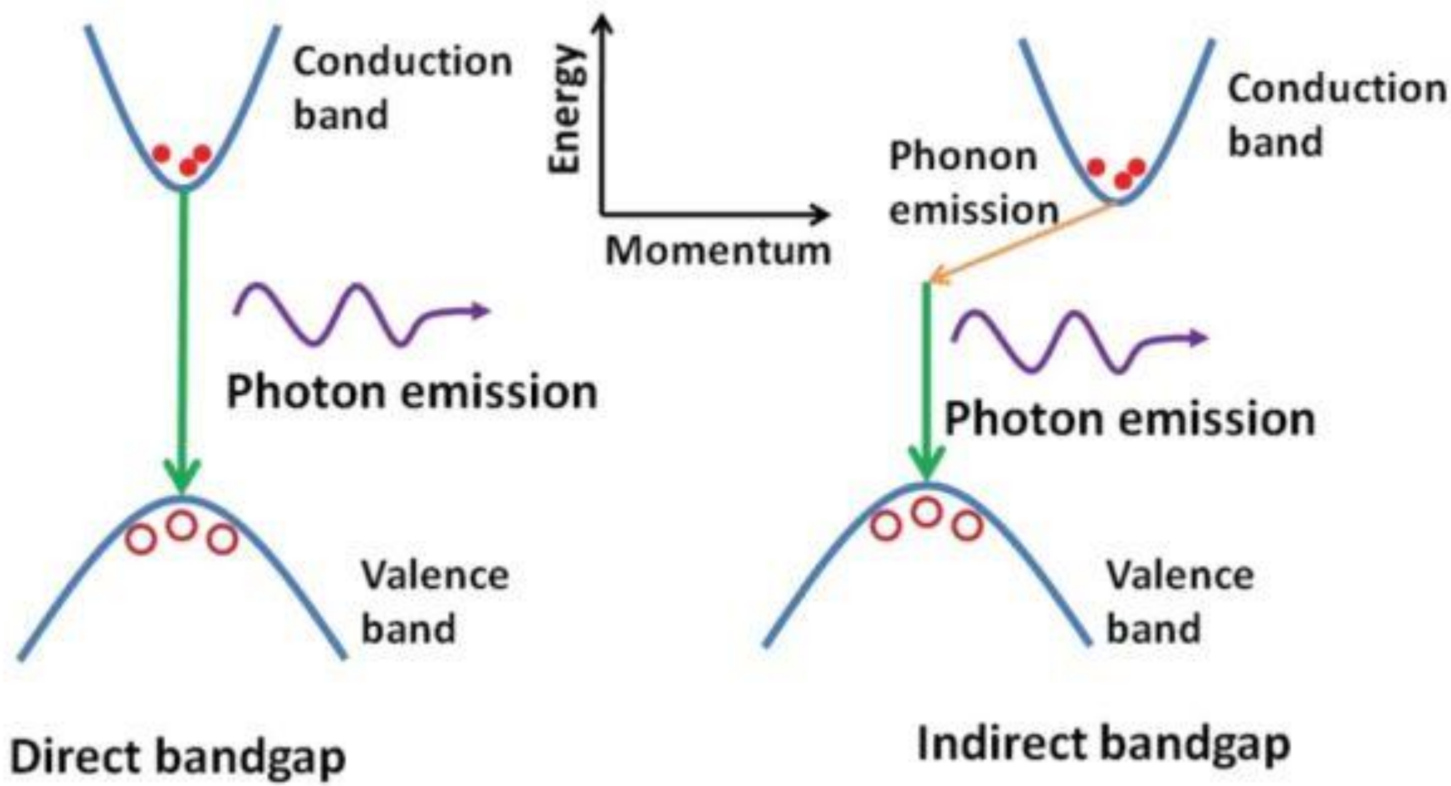
# Direct and Indirect Transition



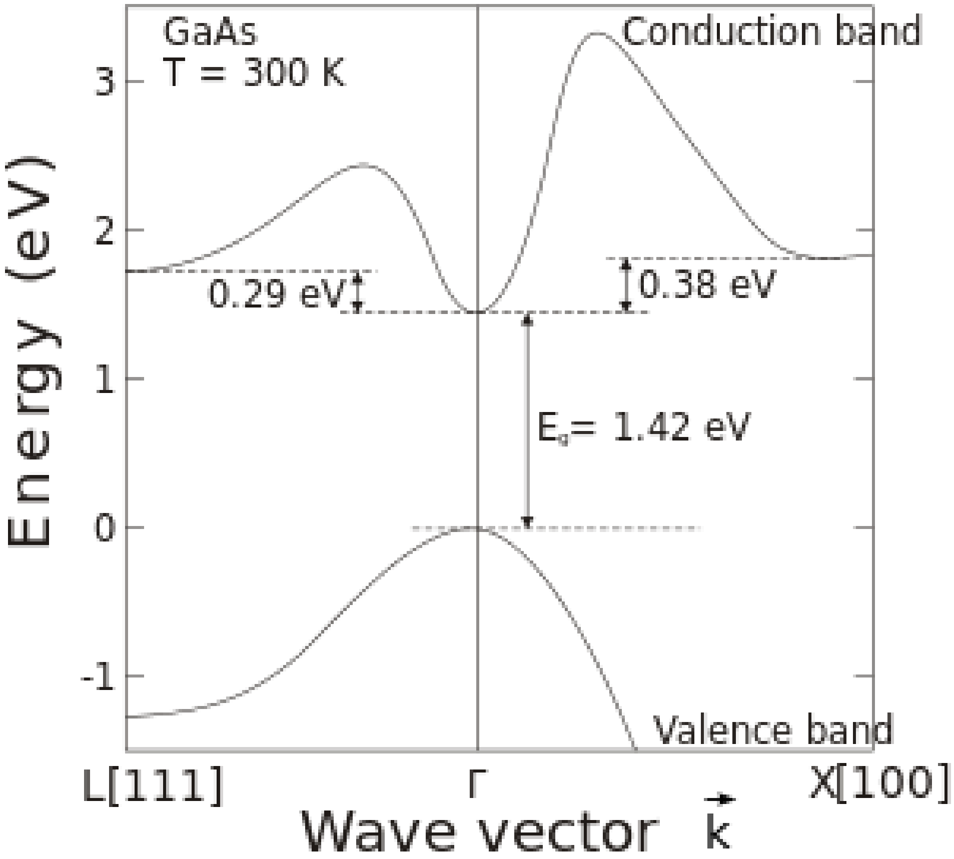

http://web.tiscali.it/decartes/phd_html/node4.html

# Direct and Indirect Bandgap




http://www.intechopen.com/books/advances-in-lasers-and-electro-optics/the-intersubband-approach-to-si-based-lasers

# GaAs Bandgap




http://www.wikiwand.com/en/Gallium_arsenide