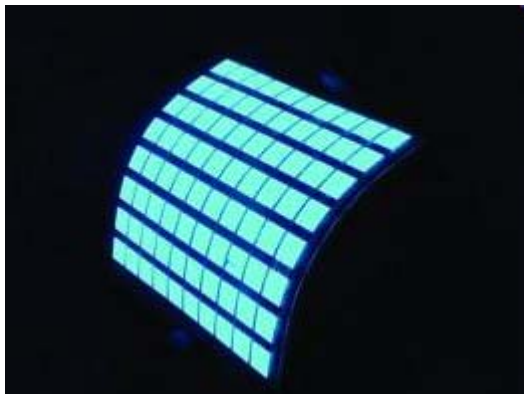
15. Optoelectronics

Jan. 29, 2020

Efficient lighting



Very efficient
Many colors possible
No toxic chemicals

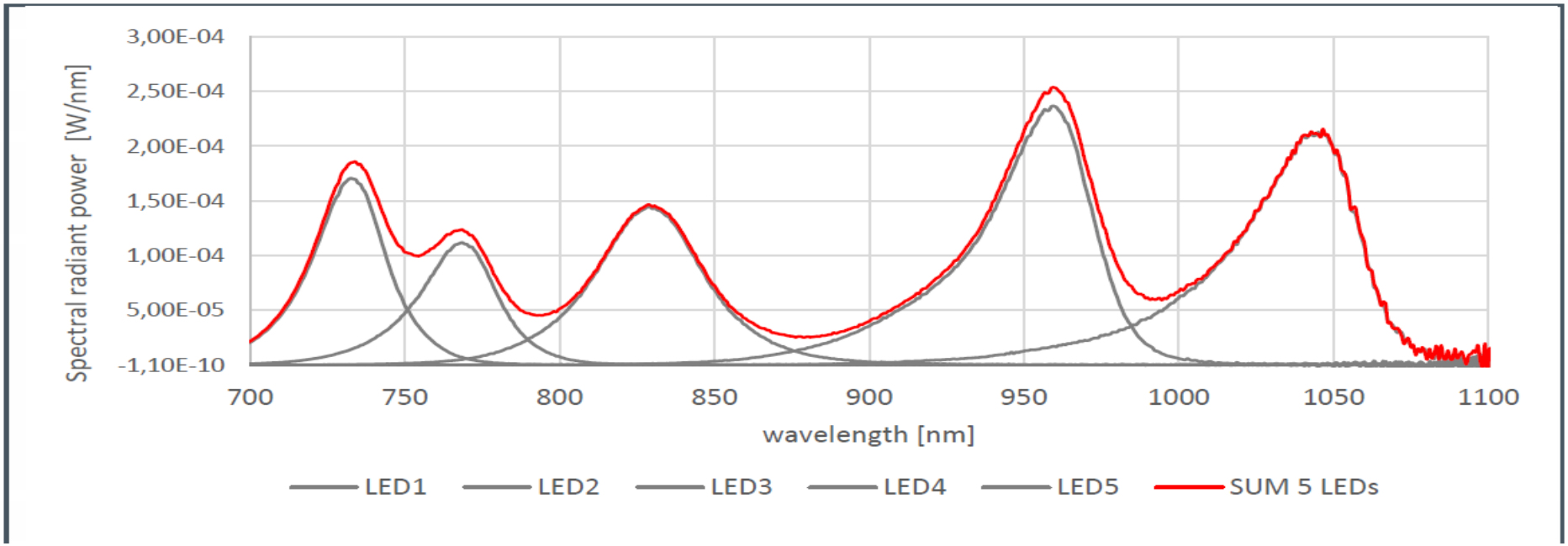
Flexible, transparent, wearable displays

Transparent AMOLED

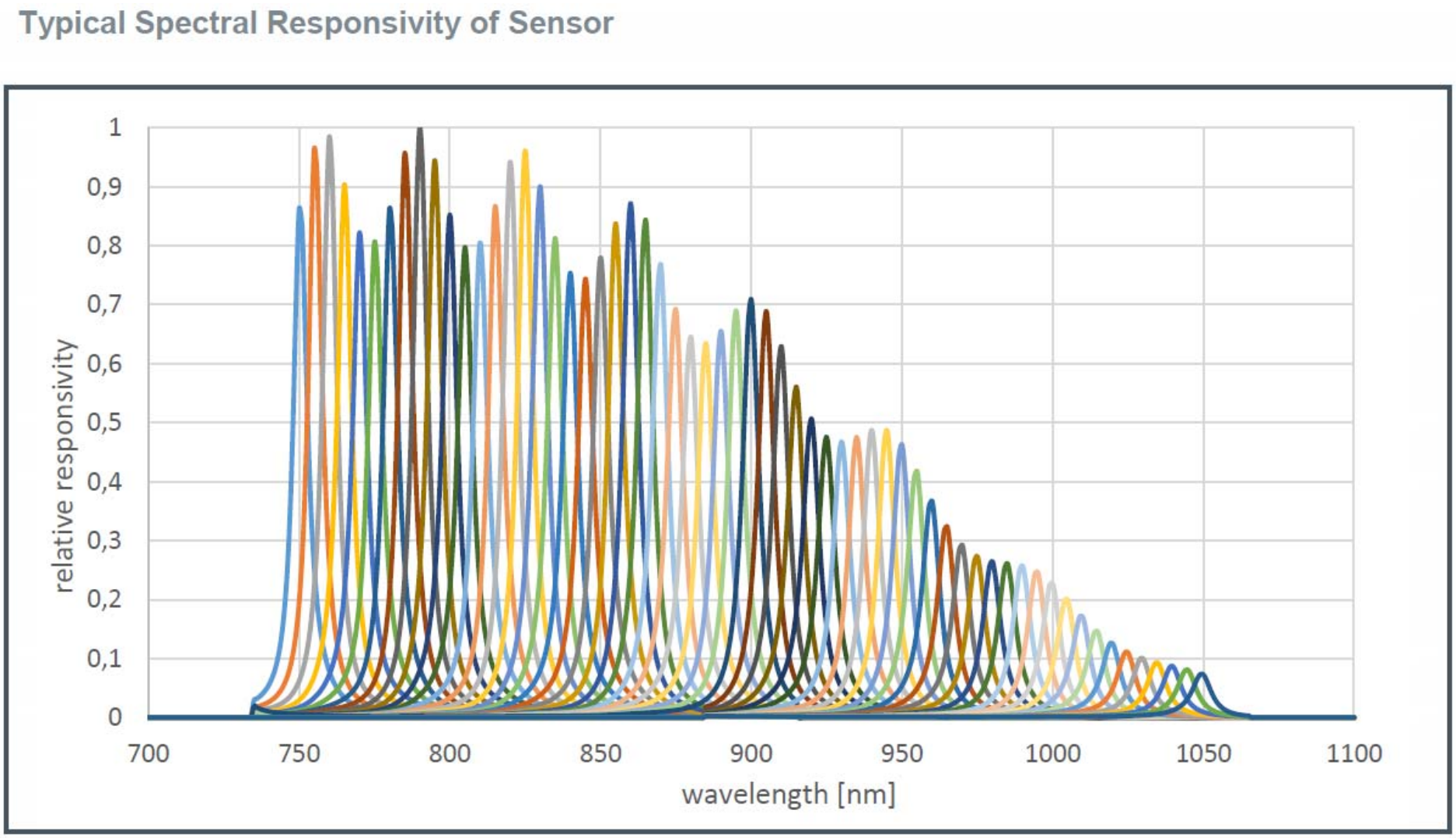
Folding display

AS7420 64-channel hyperspectral near infrared sensor

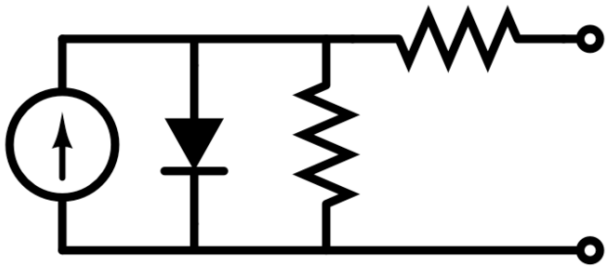
Typical LED Spectral Emission at 50mA LED current



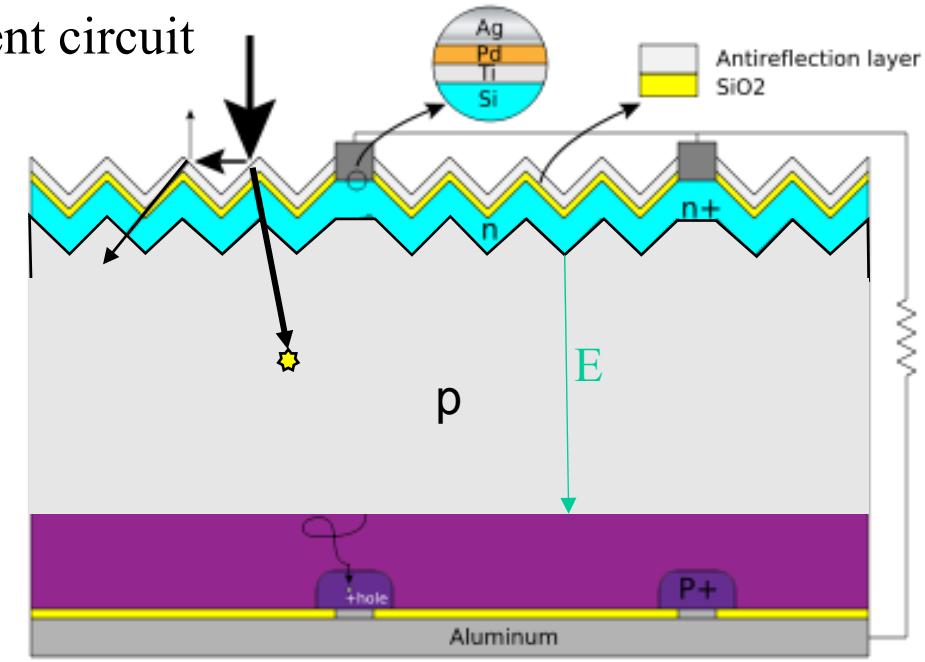
AS7420 64-channel hyperspectral near infrared sensor

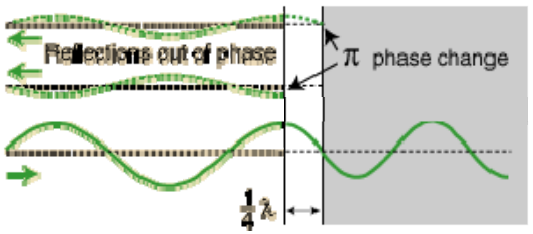


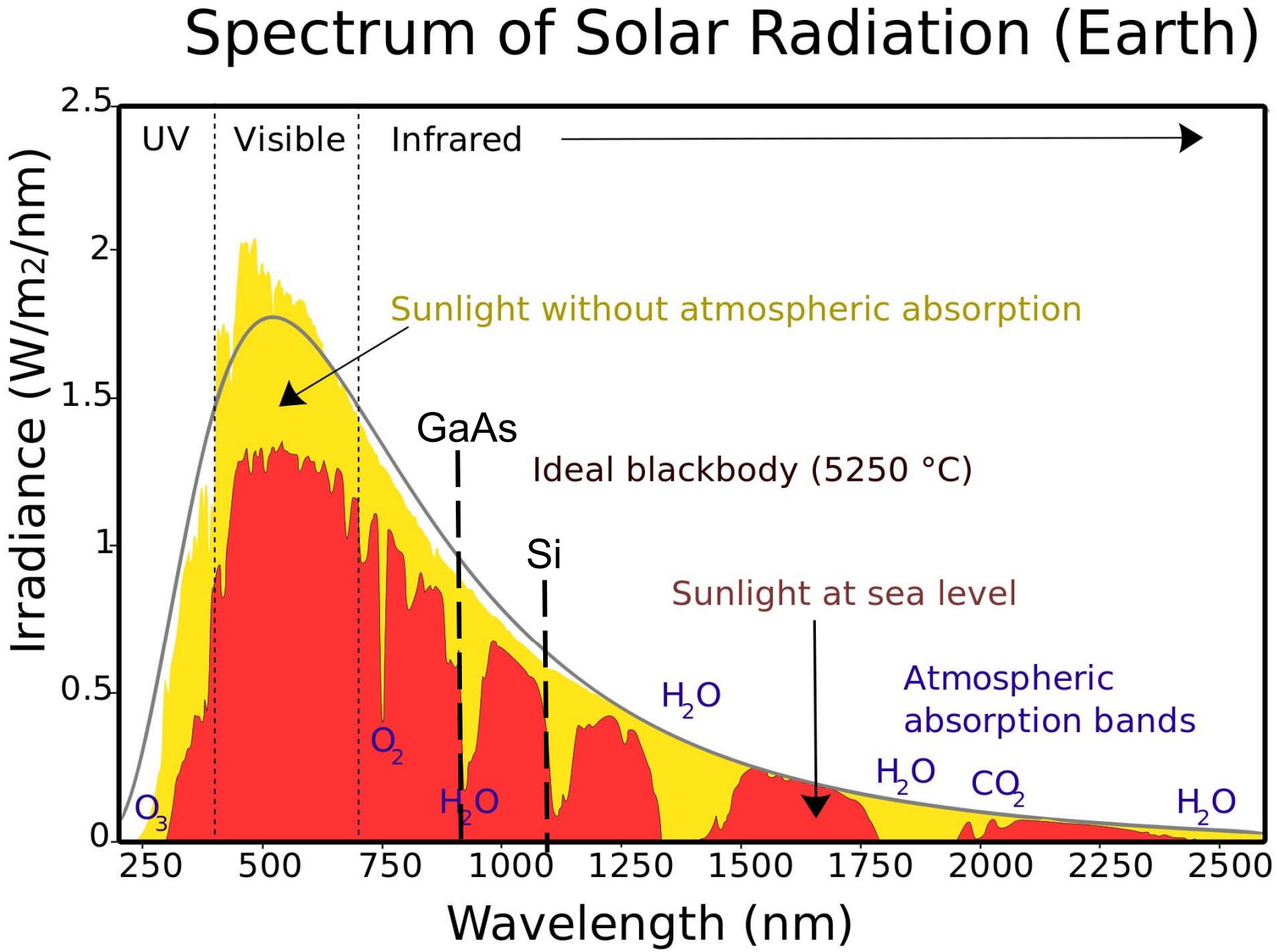
Solar cell



Equivalent circuit

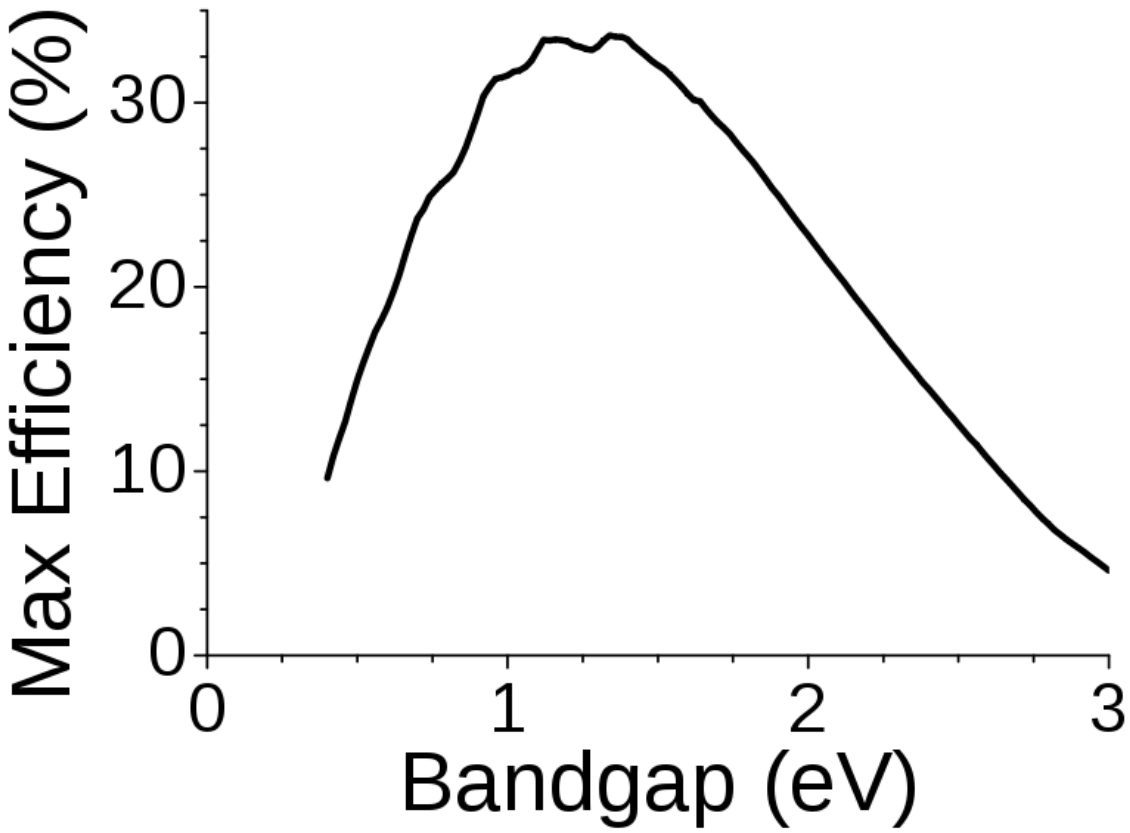




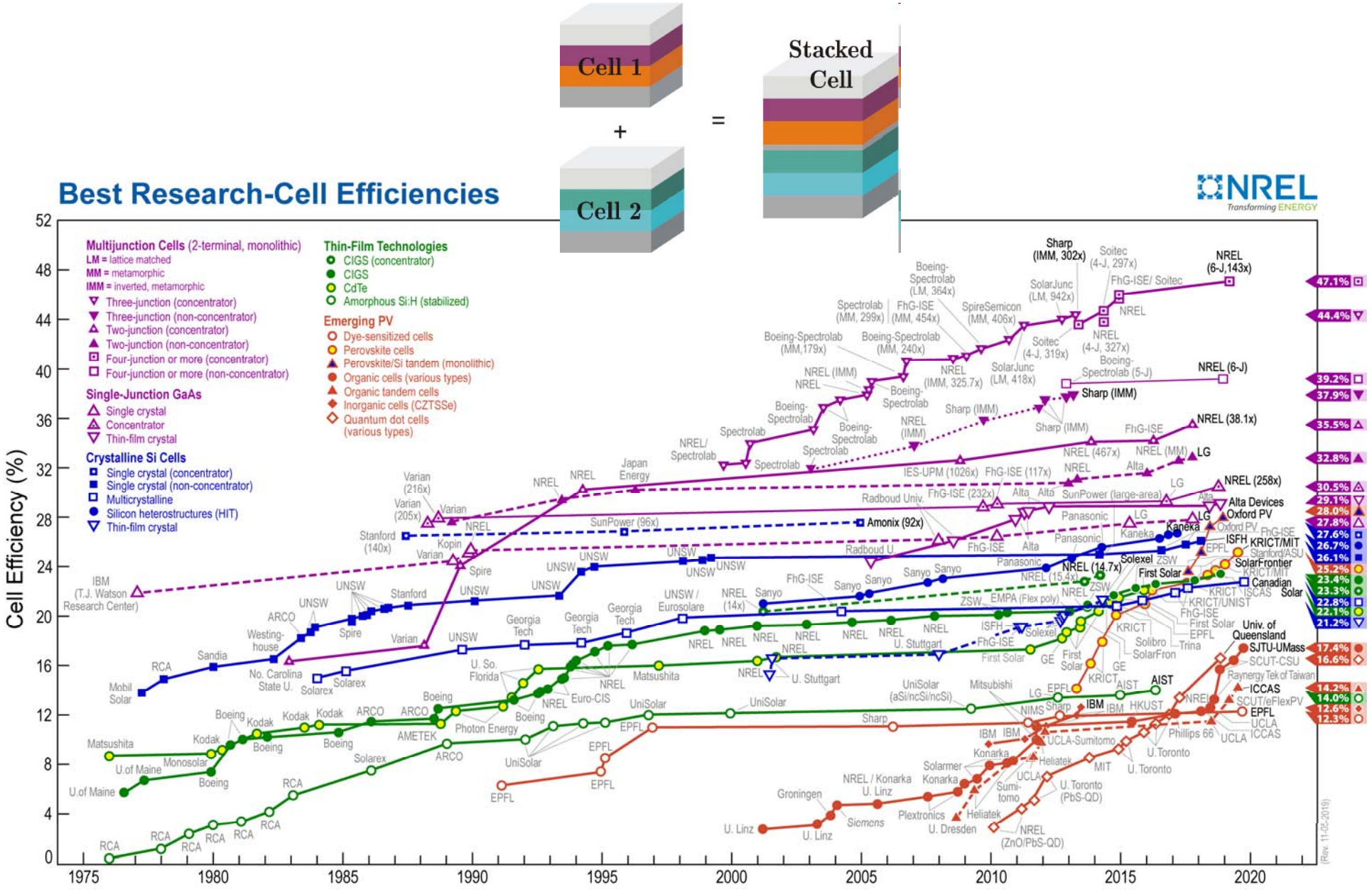


Wu, H.W. & Emadi, A & Graaf, G & Leijtens, Johan & Wolffenbuttel, R.F.. (2011). Design and Fabrication of an Albedo Insensitive Analog Sun Sensor. Procedia Engineering. 25. 527-530. 10.1016/j.proeng.2011.12.131.

Shockley–Queisser limit

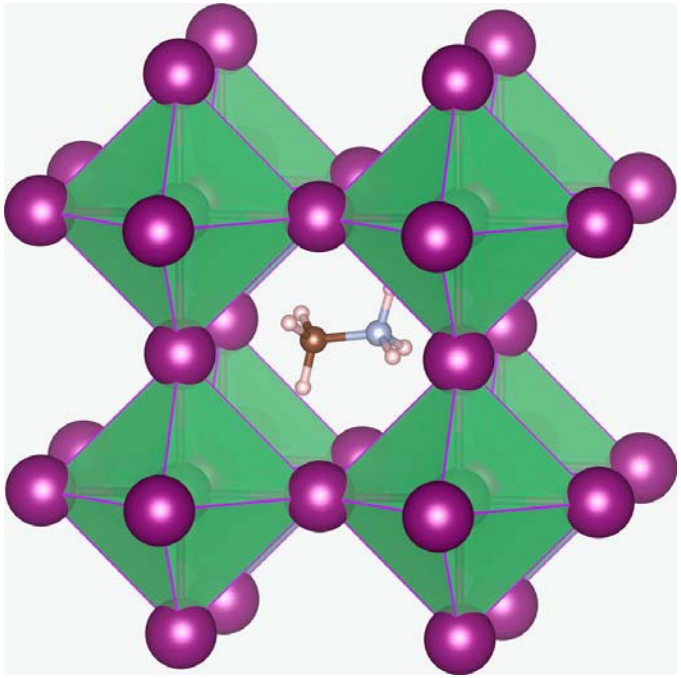


http://en.wikipedia.org/wiki/Shockley-Queisser_limit



Biofuel efficiency ~ 1%

Perovskite solar cells



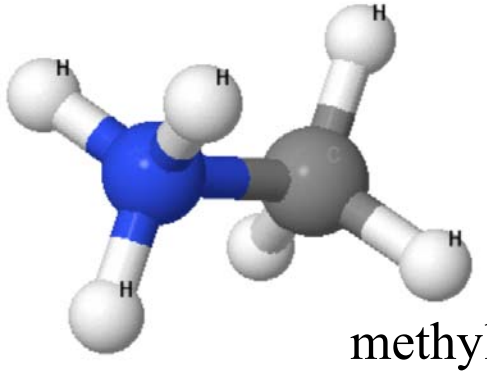
https://en.wikipedia.org/wiki/Perovskite_solar_cell#/media/File:CH3NH3PbI3_structure.png

methylammonium lead trihalide ABX_3
$CH_3NH_3PbX_3$, where X is I, Br or Cl
Optical bandgap 1.5 - 2.3 eV

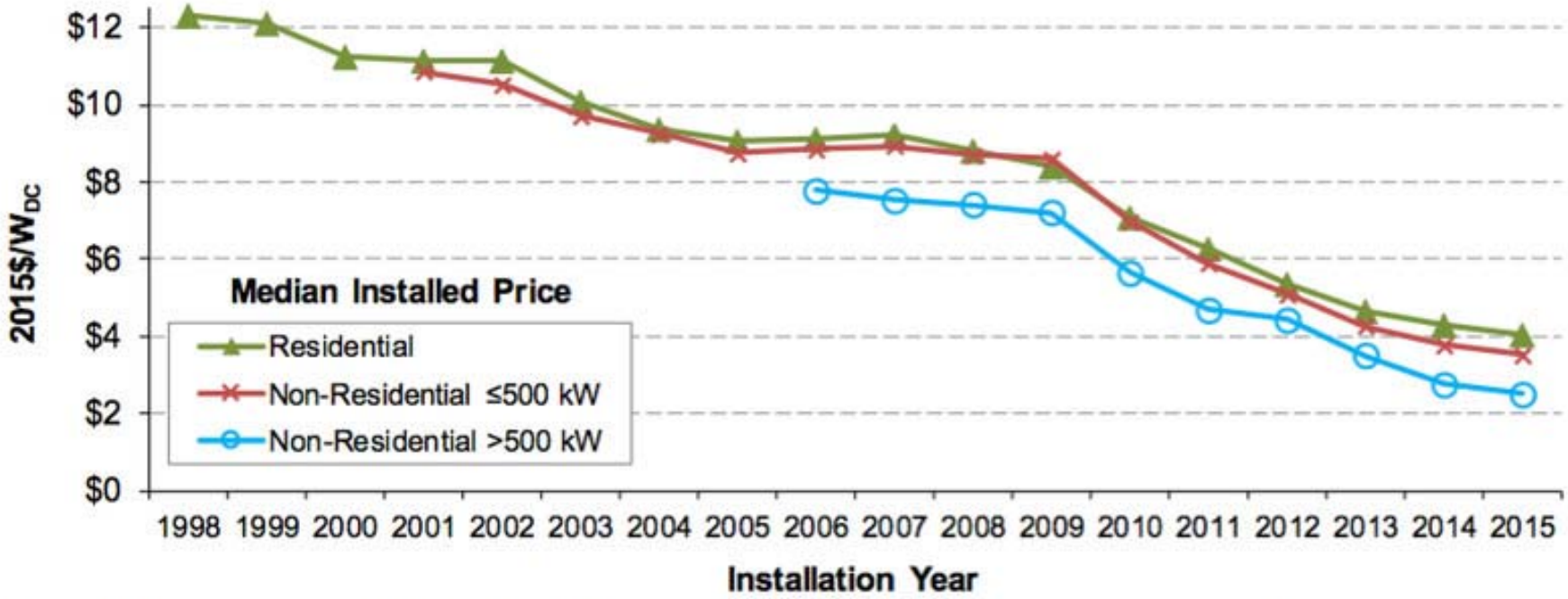
+ Cheaper to fabricate than Si solar cells.
(silicon cells require > 1000 C)

- Contains lead
Also less efficient $CH_3NH_3SnI_3$ version

- Not stable



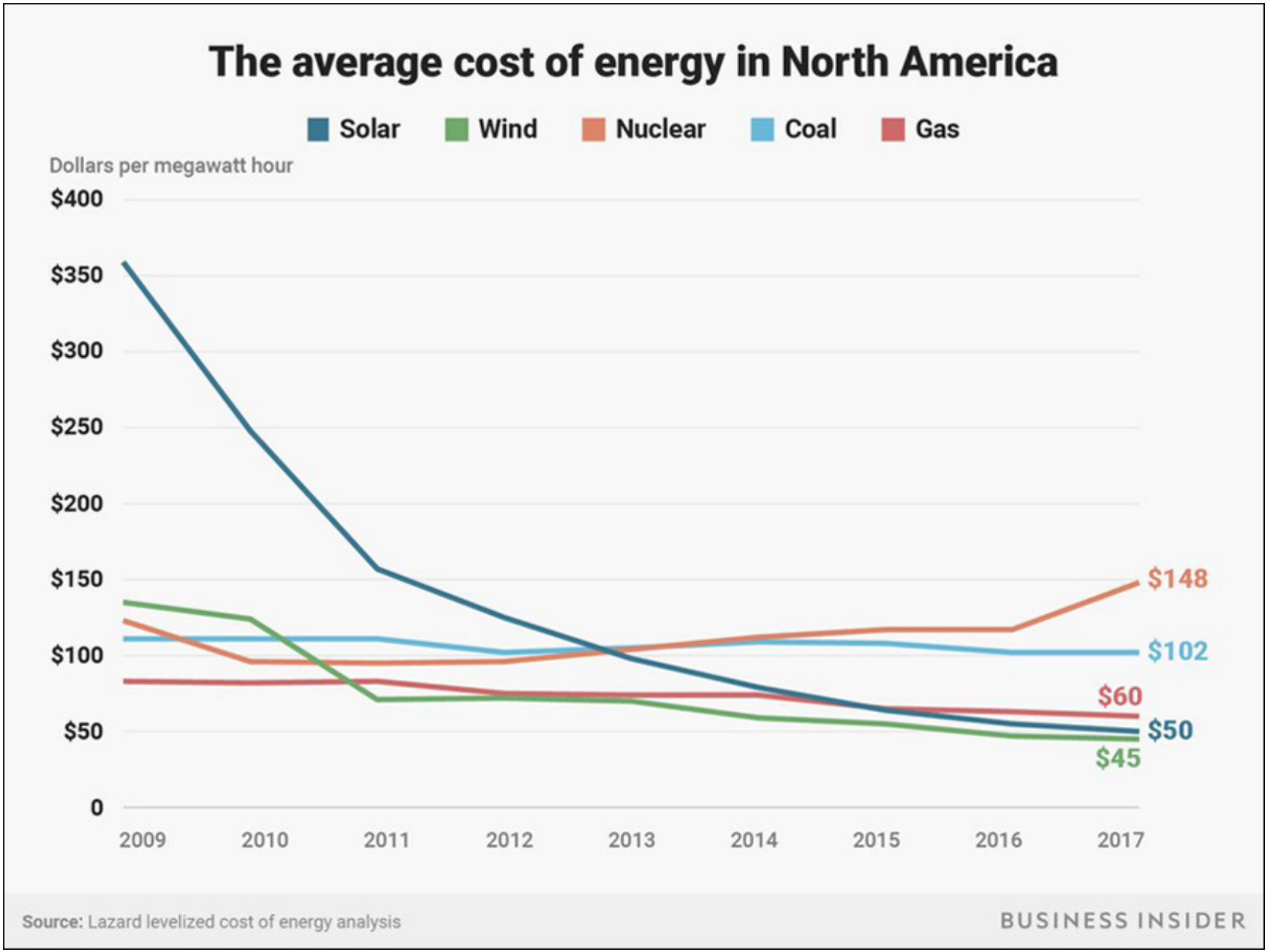
methylammonium



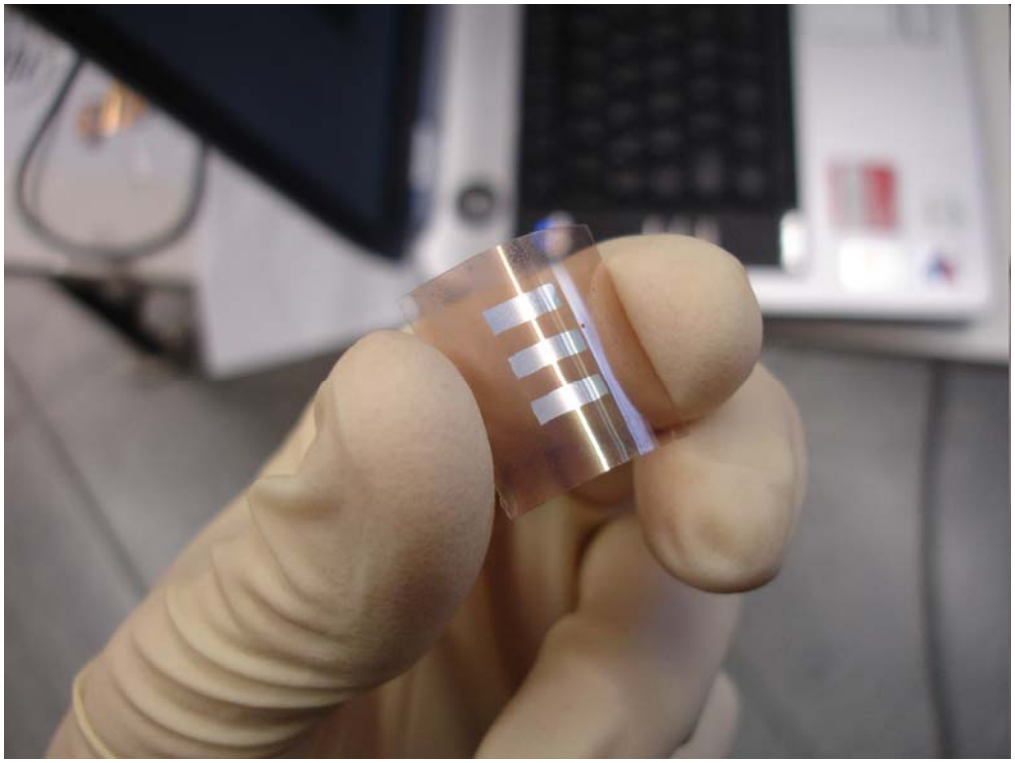
Notes: See Table 1 for sample sizes by installation year. Median installed prices are shown only if 20 or more observations are available for a given year and customer segment.

Figure 6. Median Installed Price Trends over Time

https://www.vox.com/2016/8/24/12620920/us-solar-power-costs-falling


The average cost of energy in North America
Solar
Wind
Nuclear
Coal
Gas
Dollars per megawatt hour
$400
$350
$300
$250
$200
$150
$100
$50
0
2009
2010
2011
2012
2013
2014
2015
2016
2017
$148
$102
$60
$50
$45
Source: Lazard levelized cost of energy analysis
BUSINESS INSIDER

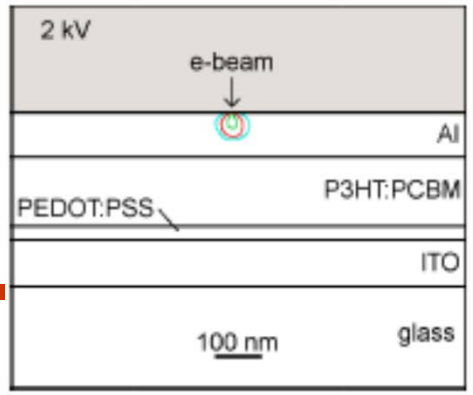
Printable solar cells



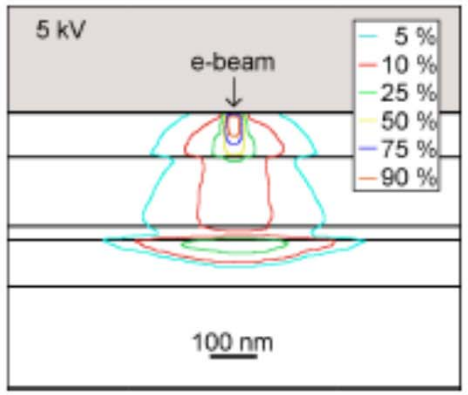
CD labor - TU Graz

Konarka

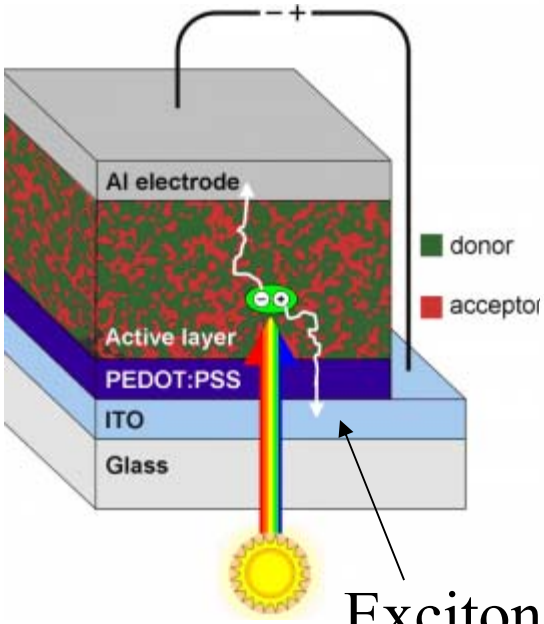
organic solar cells



(a)



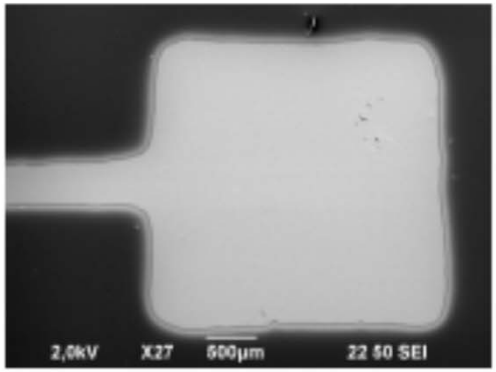
(b)



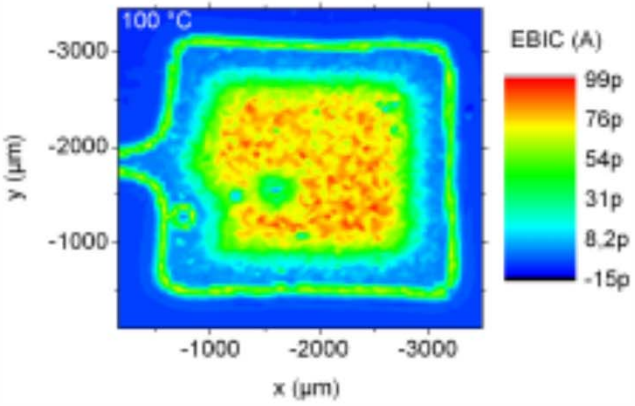
Excitons

Bulk heterojunction

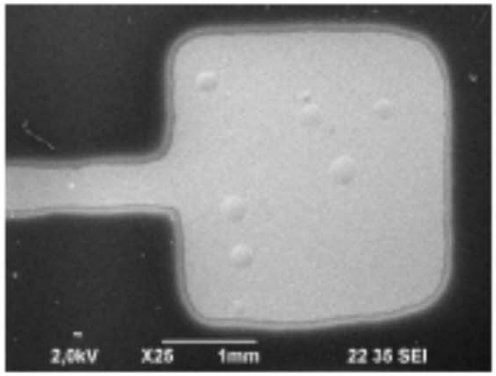
(a)



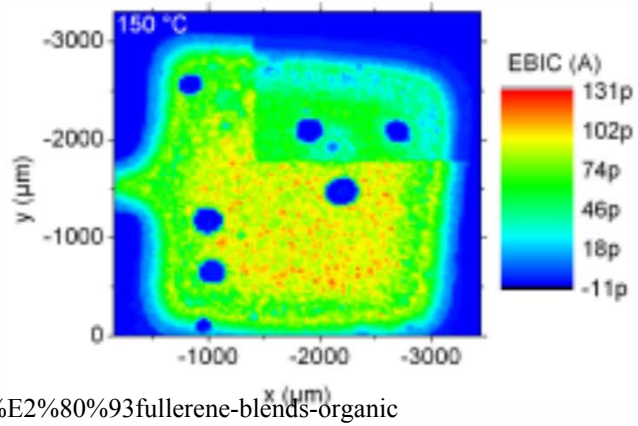
(b)



(c)

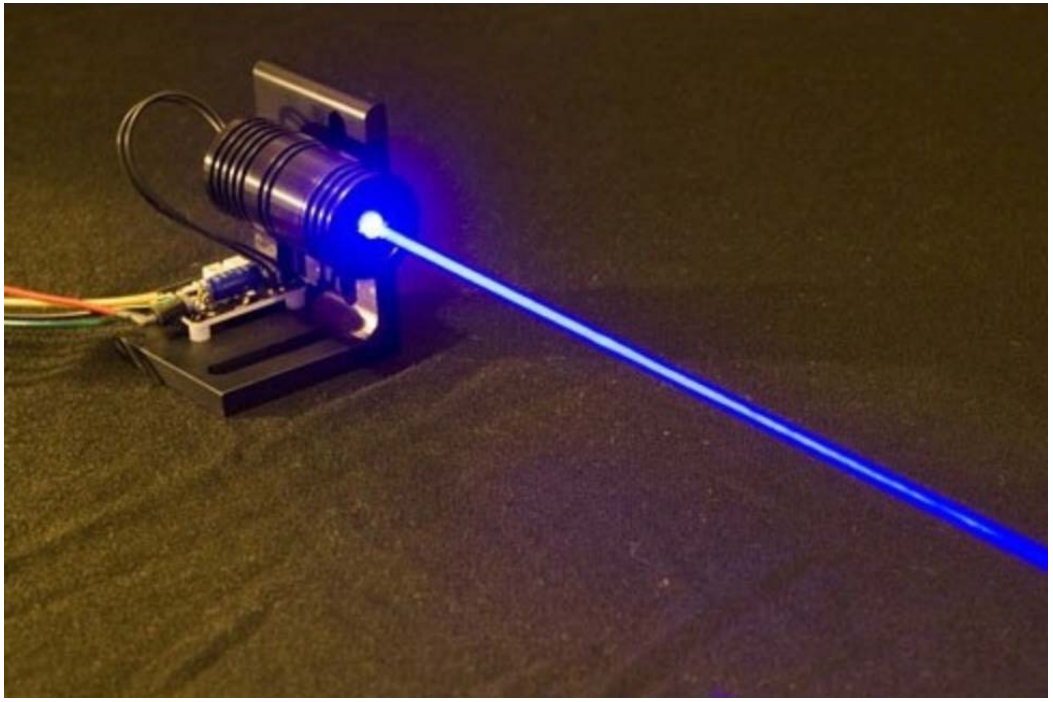


(d)



http://www-ssrl.slac.stanford.edu/science-highlight/2011/january/effects-thermal-annealing-morphology-polymer%E2%80%93fullerene-blends-organic

laser diodes



http://www.aliexpress.com/item/445nm-laser-diode/767127021.html

Shop on Google Sponsored

Laserdiode Rot 650 nm 2 mW ...
€23,99
Conrad.at

Laserdiode Rot 670 nm 5 mW U- ...
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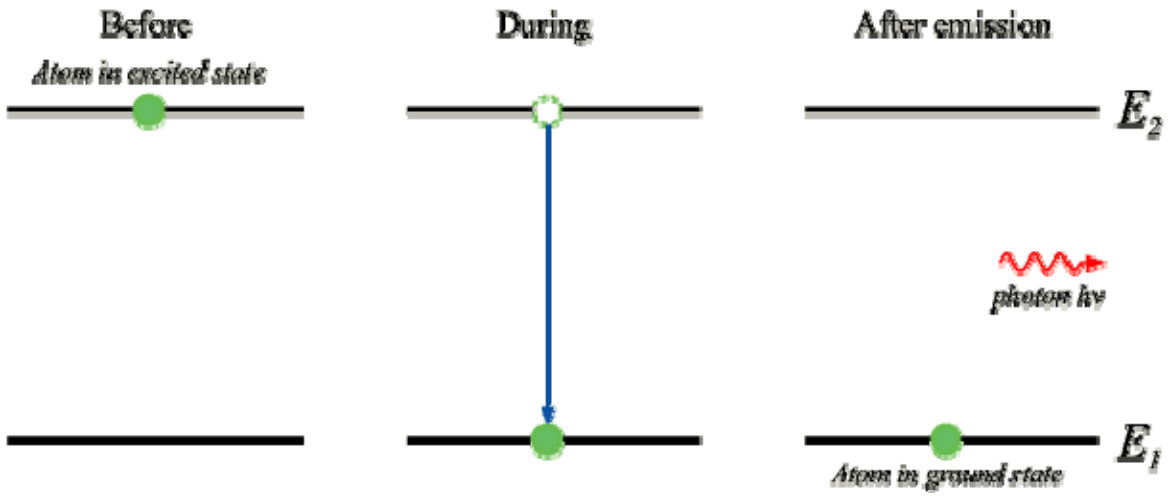
3V 6mm 5mW 650nm rote Laser-
€2,43
DX.com

Laser Components - ...
€30,72
Distrelec Österrei...

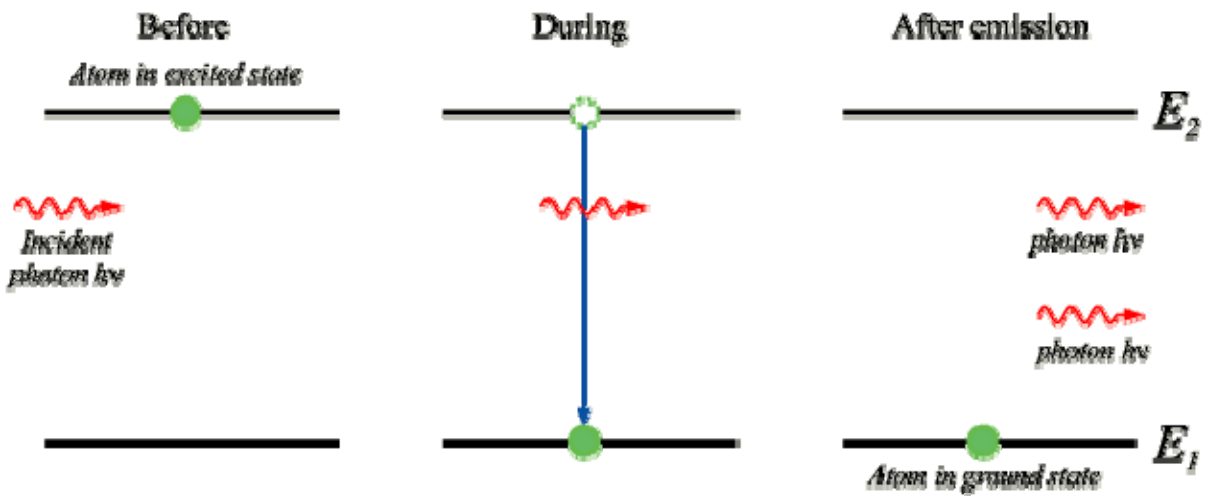
Spontaneous emission



$$h\nu = E_2 - E_1$$

Spontaneous emission dominates in fluorescent lighting and light emitting diodes. In a gas, the conservation of momentum is easily maintained. For a semiconductor, a direct bandgap material is necessary.

Stimulated emission



Stimulated emission is responsible for the coherent light of lasers.

$$W_{\text{stimulated}}(\omega) = W_{\text{spontaneous}}(\omega) \cdot n_{ph}(\omega)$$

laser diodes

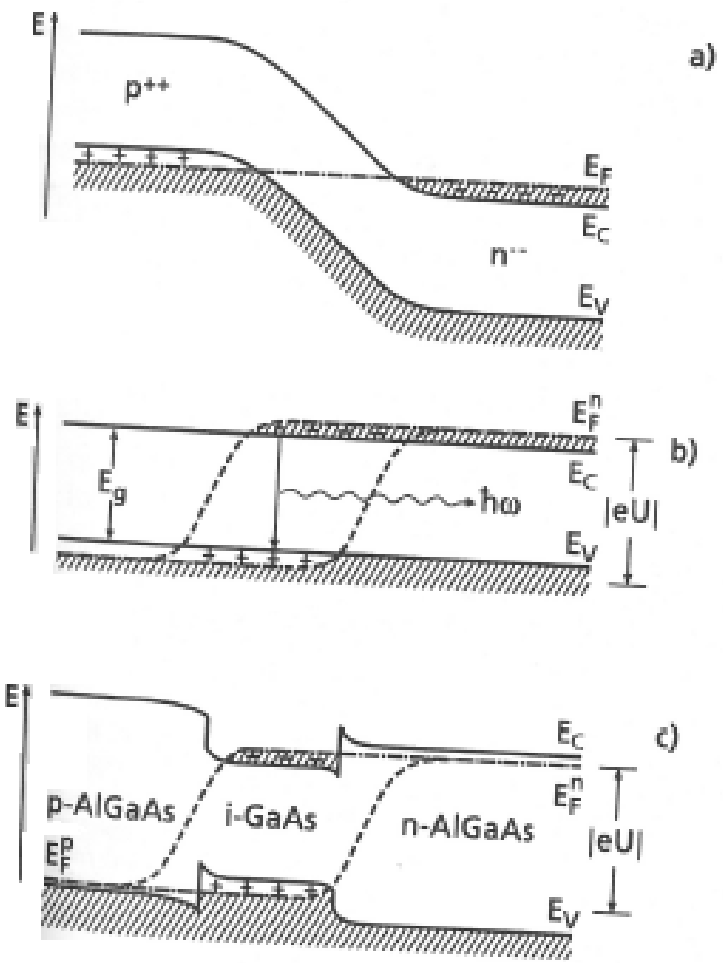
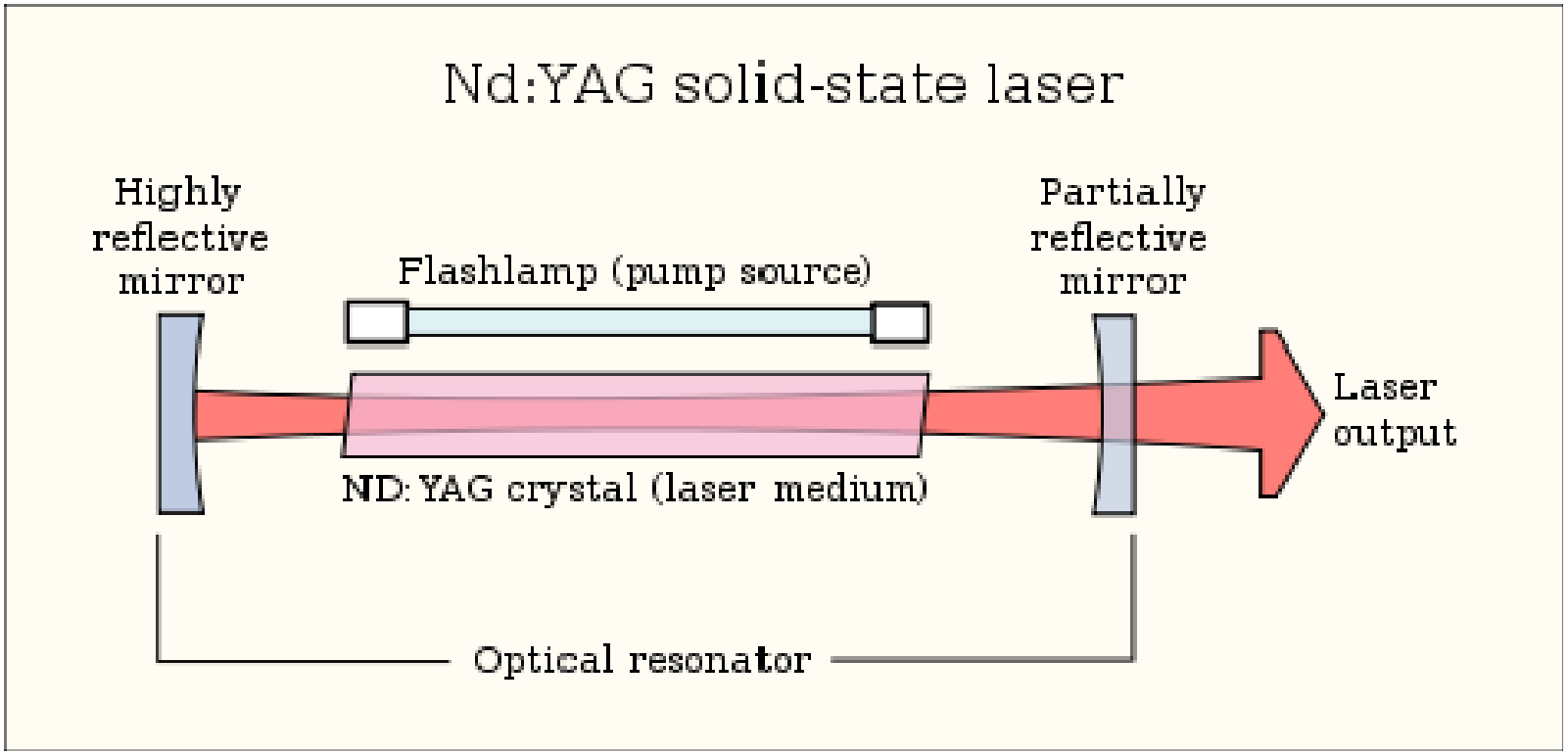


Fig. 12.37. Electronic band schemes $E(x)$ of pn-semiconductor laser structures along a direction x perpendicular to the layer structure: **(a)** Degenerately doped $p^{++}n^{--}$ junction without external bias (thermal equilibrium); **(b)** same $p^{++}n^{--}$ junction with maximum bias U in forward direction; **(c)** double-heterostructure pin junction of p-AlGaAs/i-GaAs/n-AlGaAs with maximum bias U in forward direction. E_F^n, E_F^p are the quasi-Fermi levels in the n- and p-region, respectively; E_C and E_V are conduction and valence band edges

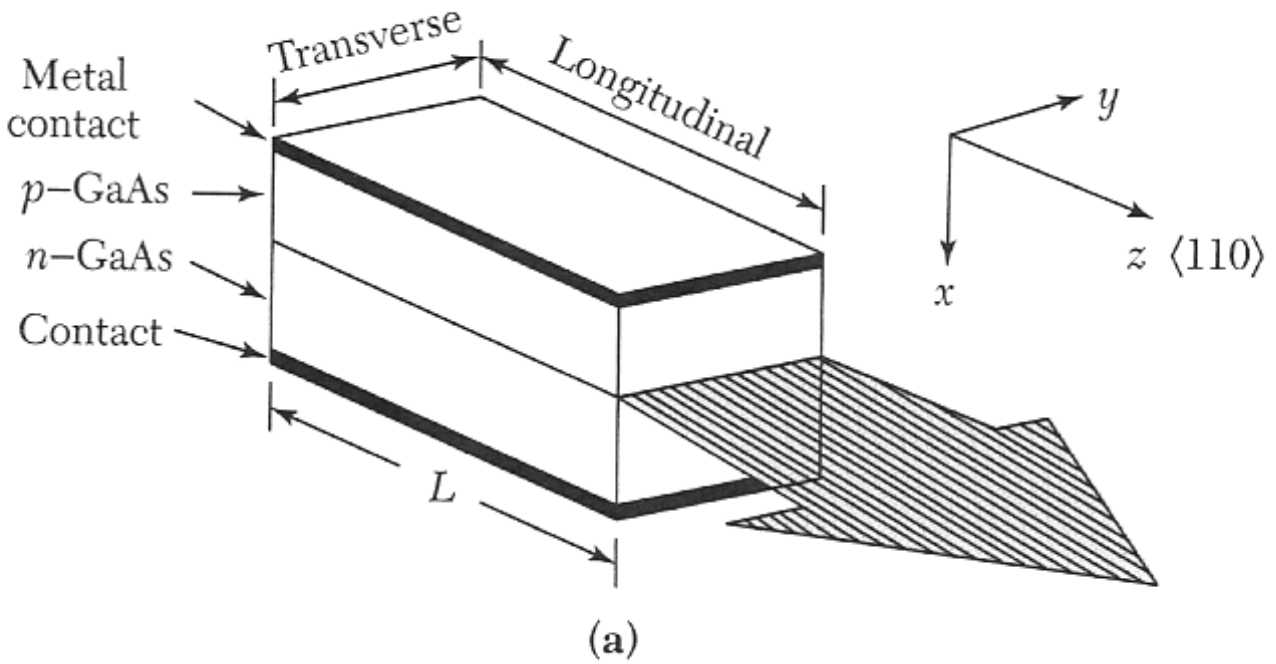
Ibach & Lueth, *Solid-State Physics*

Optical cavity



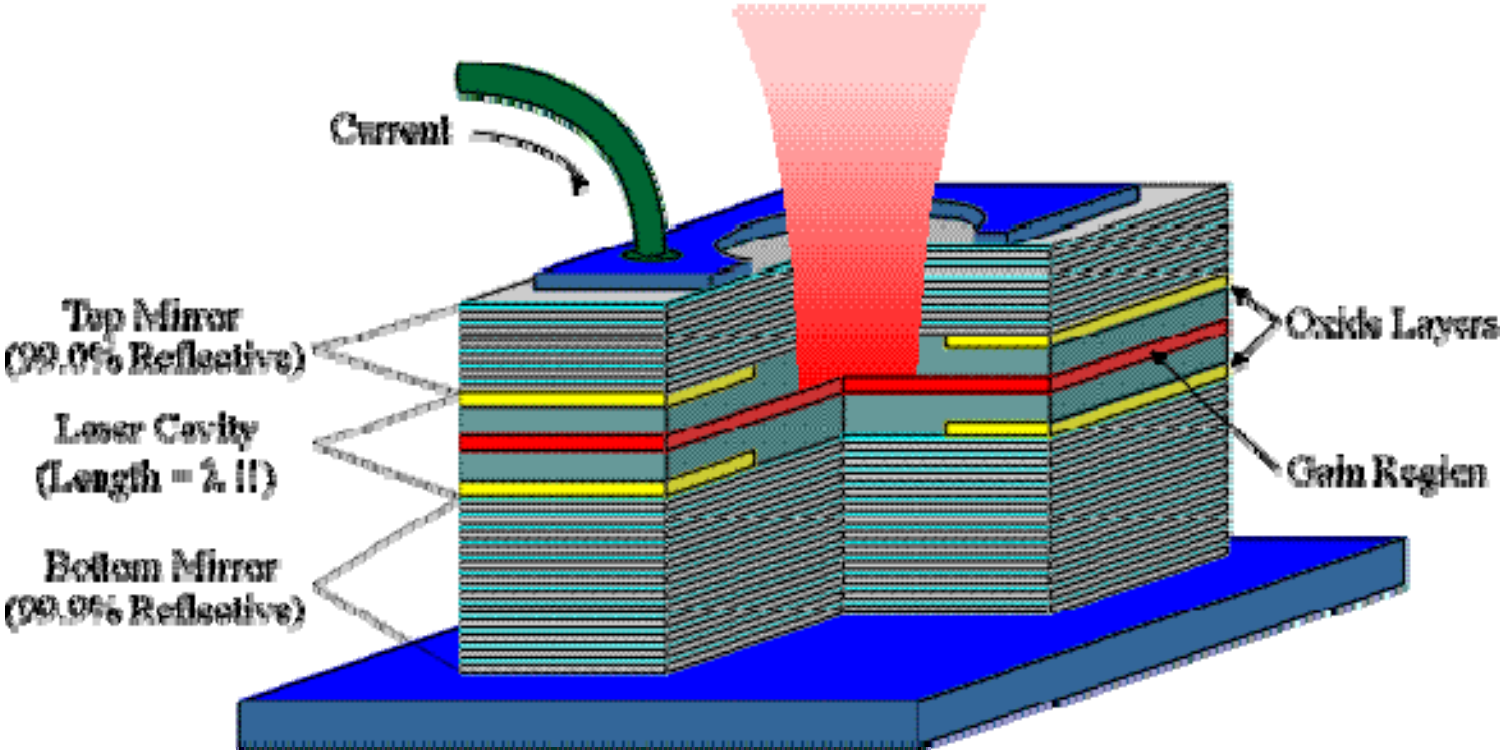
https://en.wikipedia.org/wiki/Laser_construction#/media/File:Lasercons.svg

Laser diode

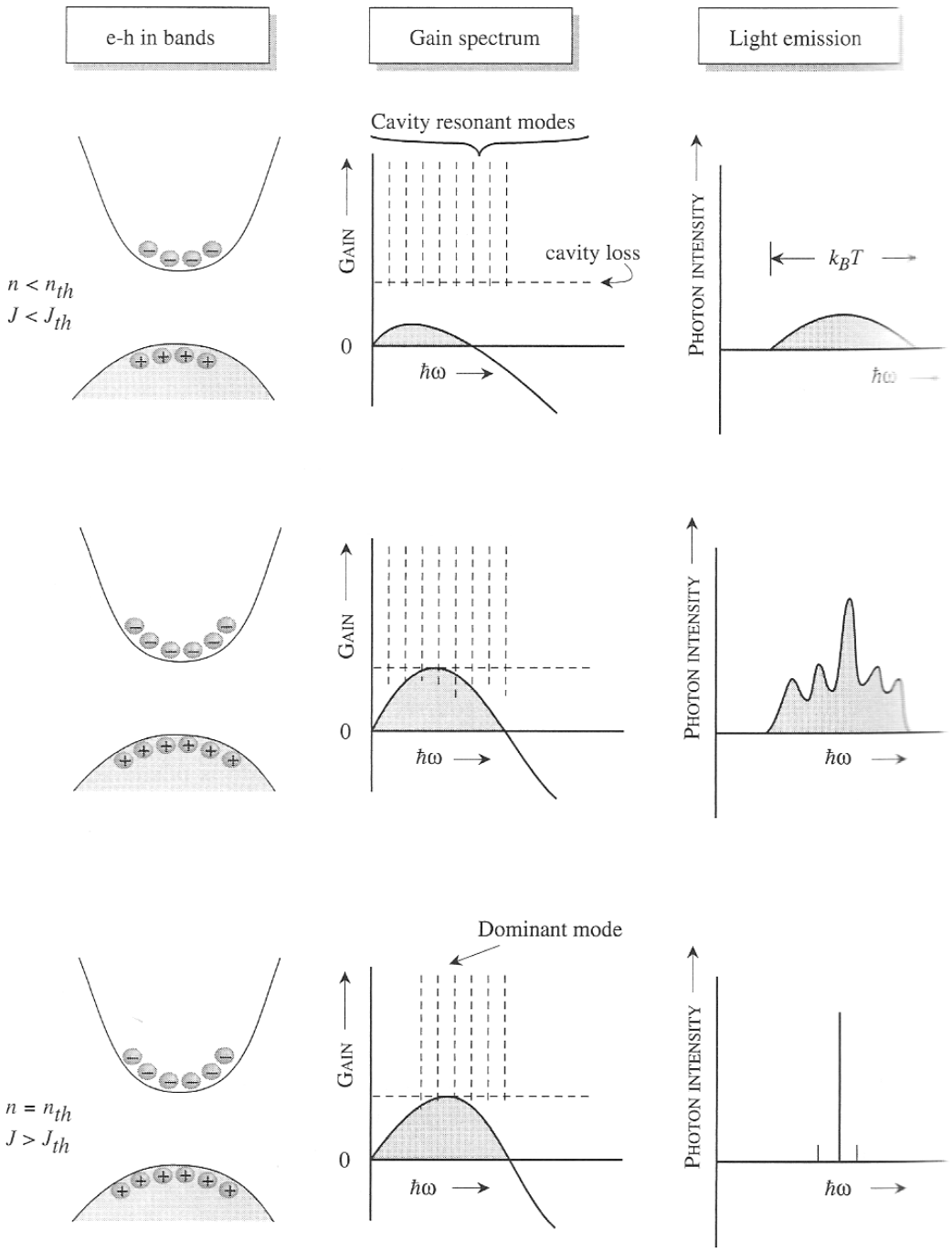


The faces of the crystal are cleaved to make mirrors.

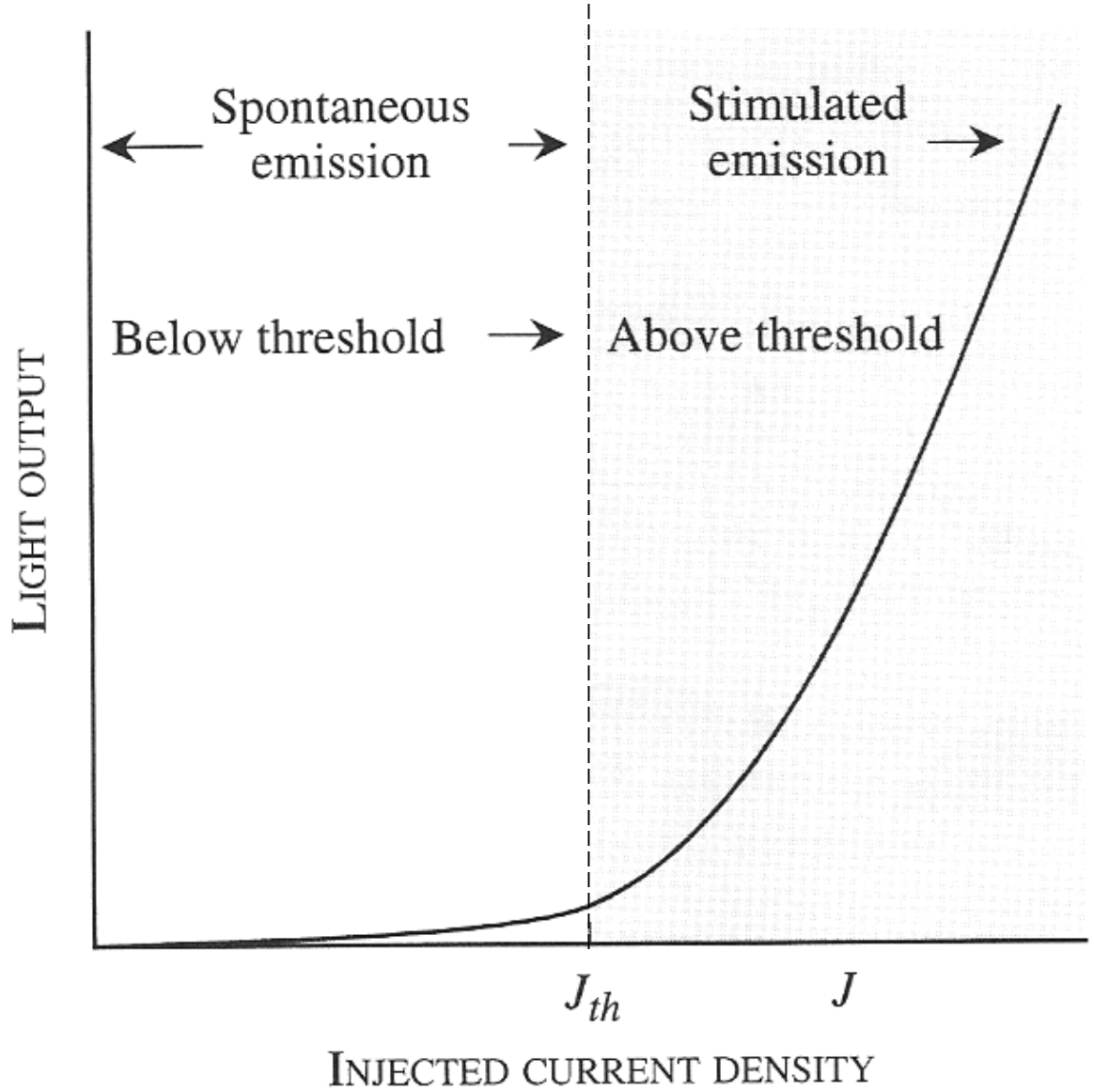
Vertical-cavity surface-emitting laser (VCSEL)



http://wwwold.fi.isc.cnr.it/users/giovanni.giacomelli/Semic/Samples/samples.html

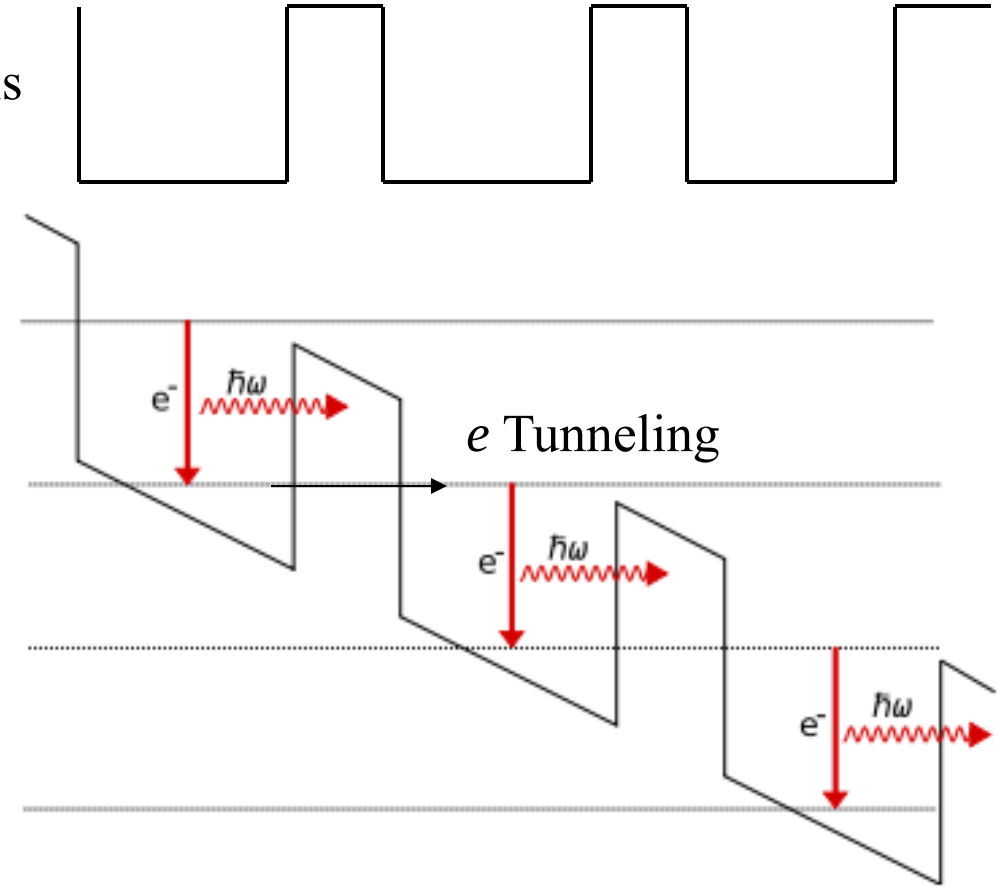

e-h in bands
Gain spectrum
Light emission
Cavity resonant modes
cavity loss
$n < n_{th}$
$J < J_{th}$
GAIN
0
$\hbar\omega$
PHOTON INTENSITY
$k_B T$
$n = n_{th}$
$J > J_{th}$
Dominant mode

Stimulated emission



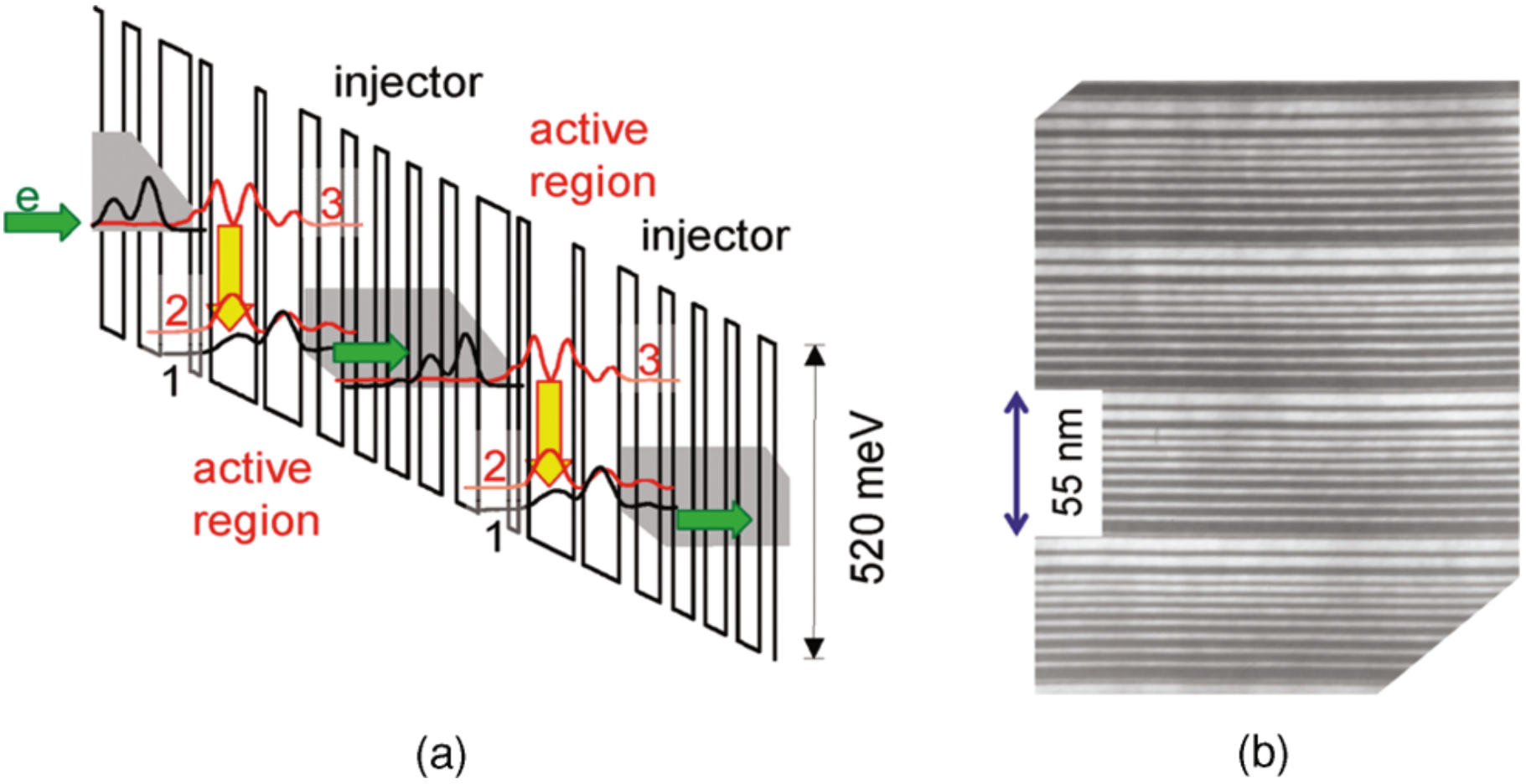
Quantum cascade lasers

Quantum wells



Energy levels depend on the width of the wells so lasers can be made at many frequencies (mid to far infrared 2.75 - 250 μm).
Many colors can be made with one materials system.
Window in atmosphere at 5 μm used for point-to-point communications.

Quantum cascade lasers



http://opticalengineering.spiedigitallibrary.org/article.aspx?articleid=1096486