Light Emitting Diodes

Outline

- Luminescence Spectra of Atoms

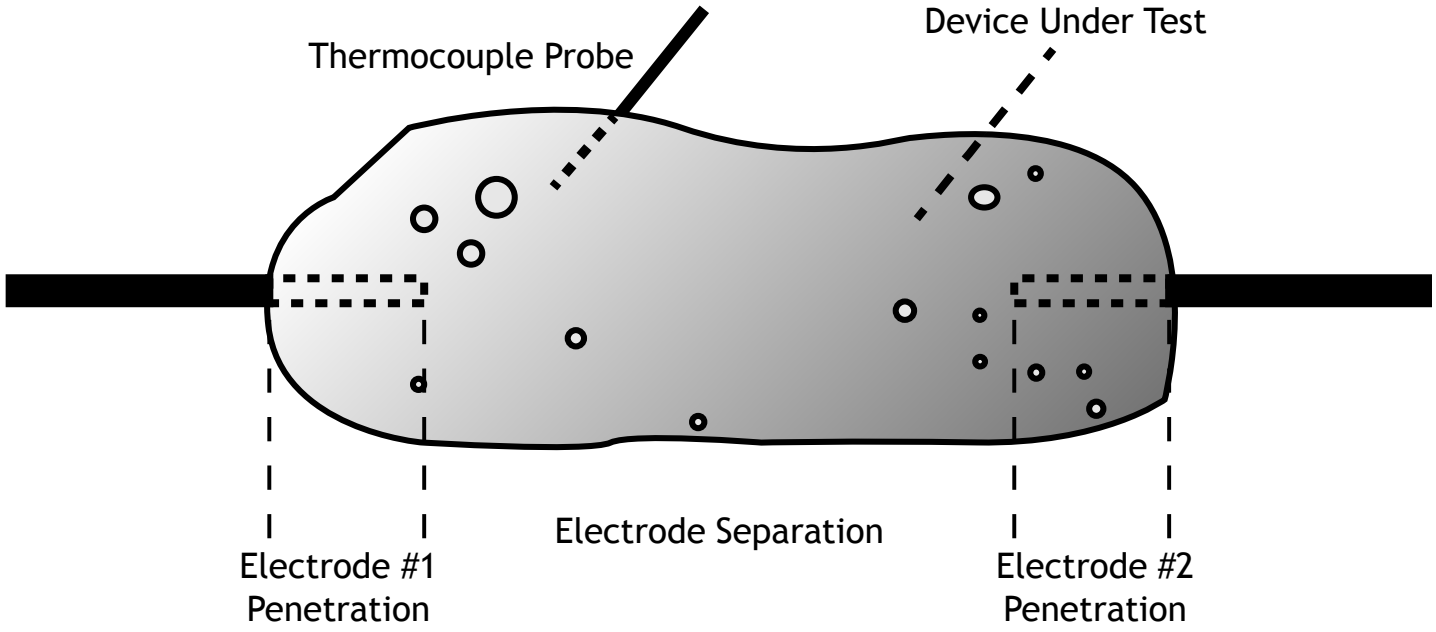
- LEDs
  - . p-n Junction
  - . Light Outcoupling

- Organic LEDs
- Quantum Dots in LEDs

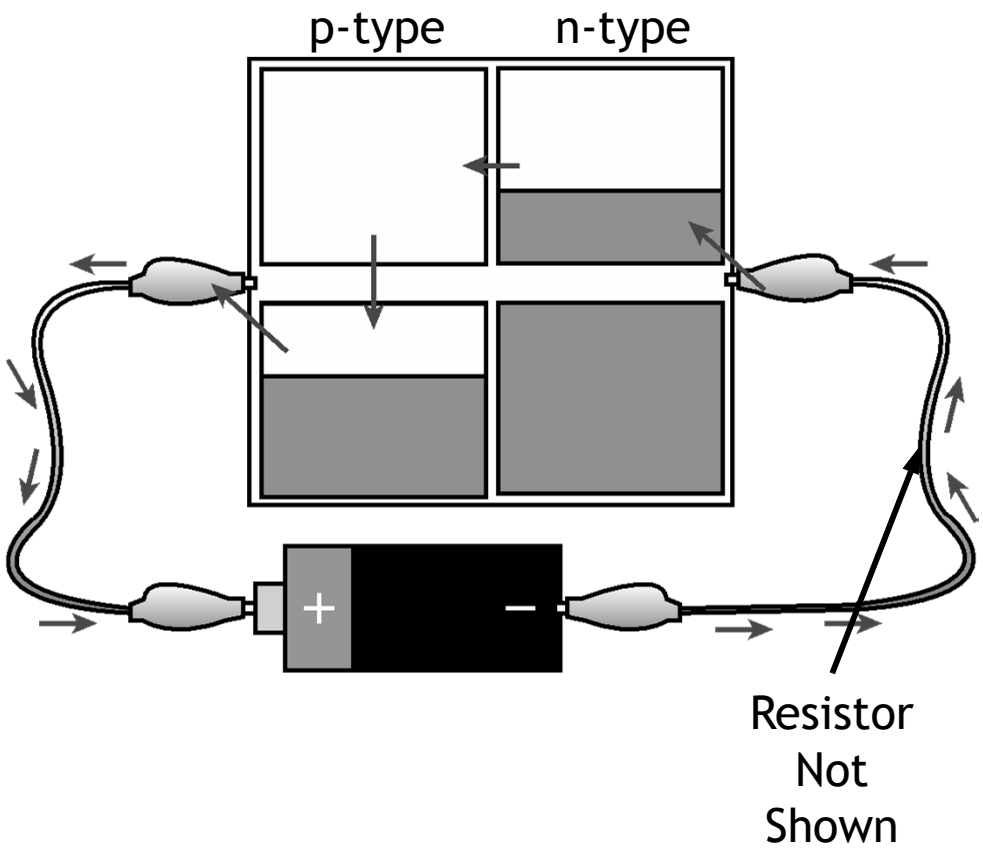
“Characterization of Organic Illumination Systems”
April 1, 1989, Hamburgen *et al.*

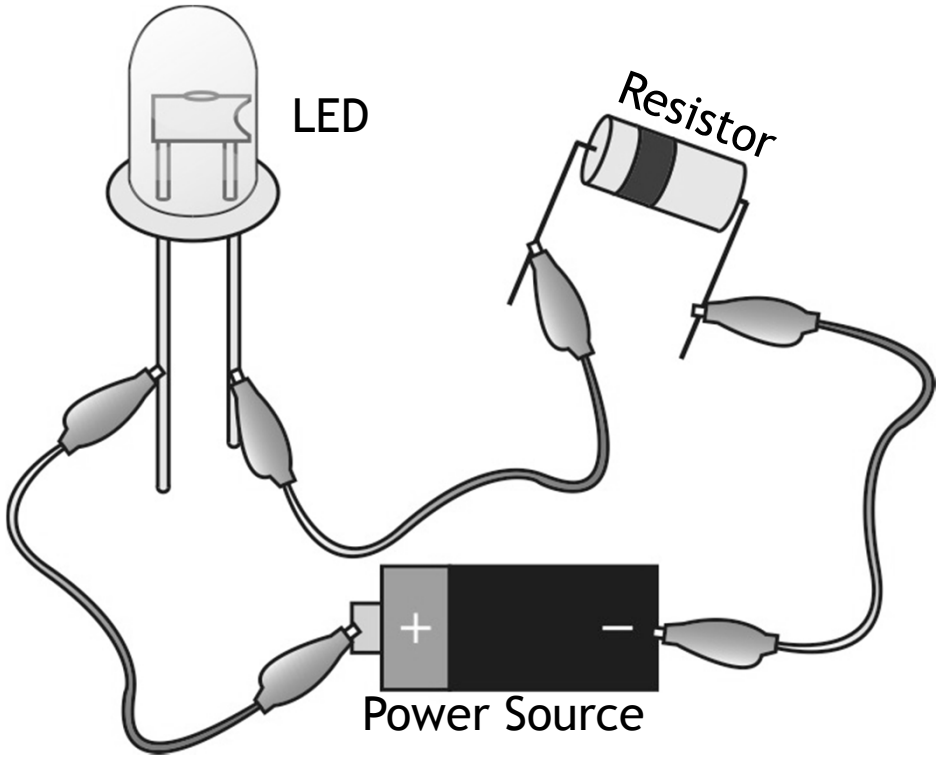
Dimensions in inches				
Subject	Electrode Orientation	Electrode Separation	Electrode #1 Penetration	Electrode #2 Penetration
Bok Choy	parallel	0.5	0.5	0.5
Mandarin Orange	parallel	0.38	0.38	0.38
Cornichon	axial	0.5	0.5	0.5
Kosher Pickle	axial	2.5	1.0	1.5
Dill Pickle	axial	2.5	1.0	1.5

Electrode Position:



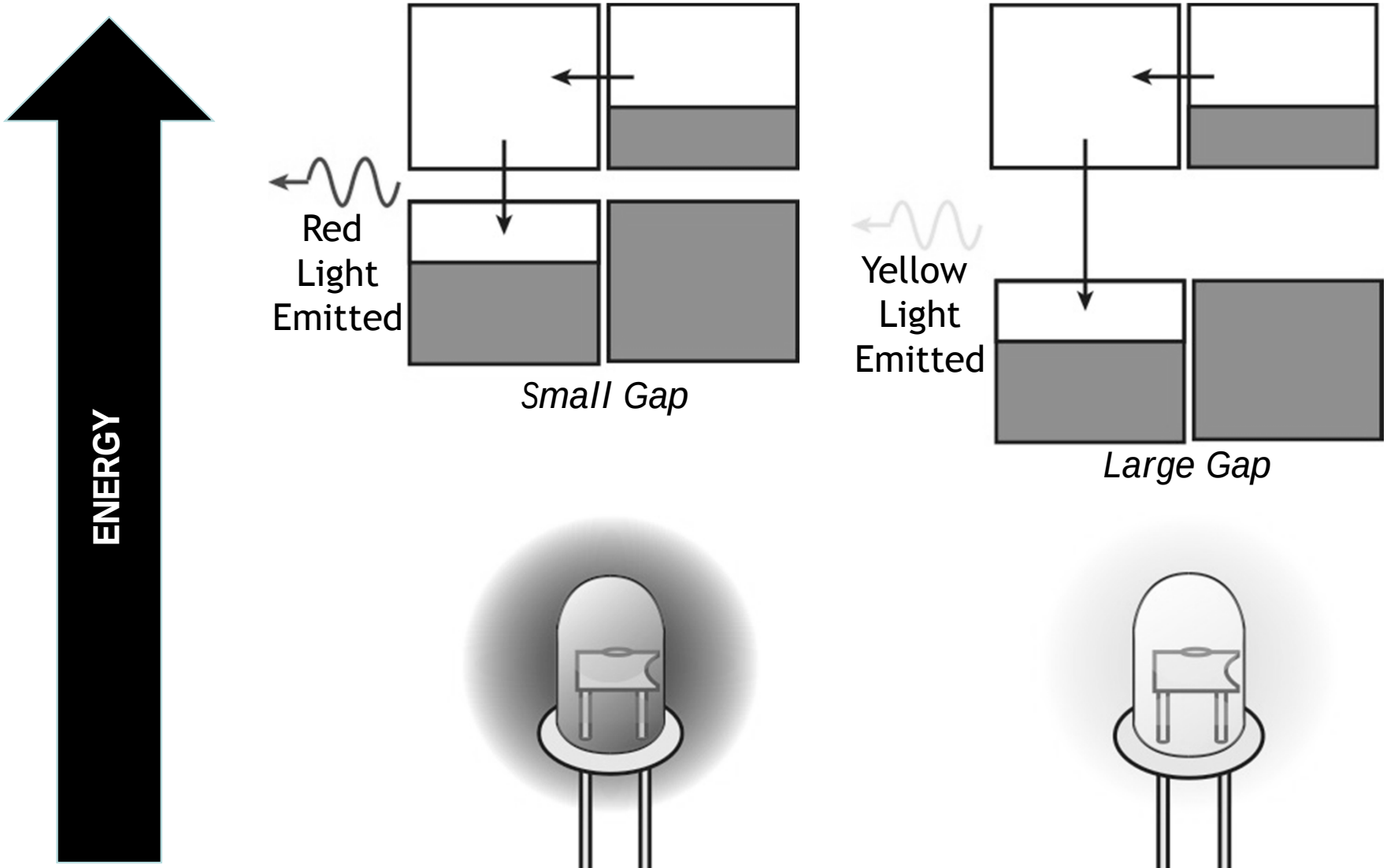
p-n Junctions and LEDs



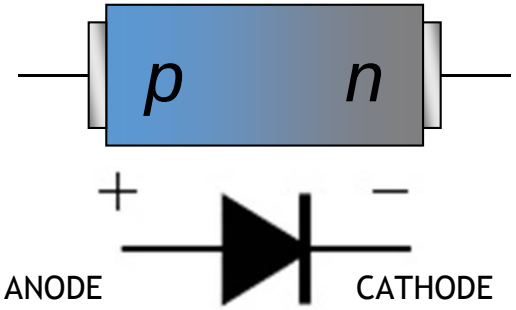


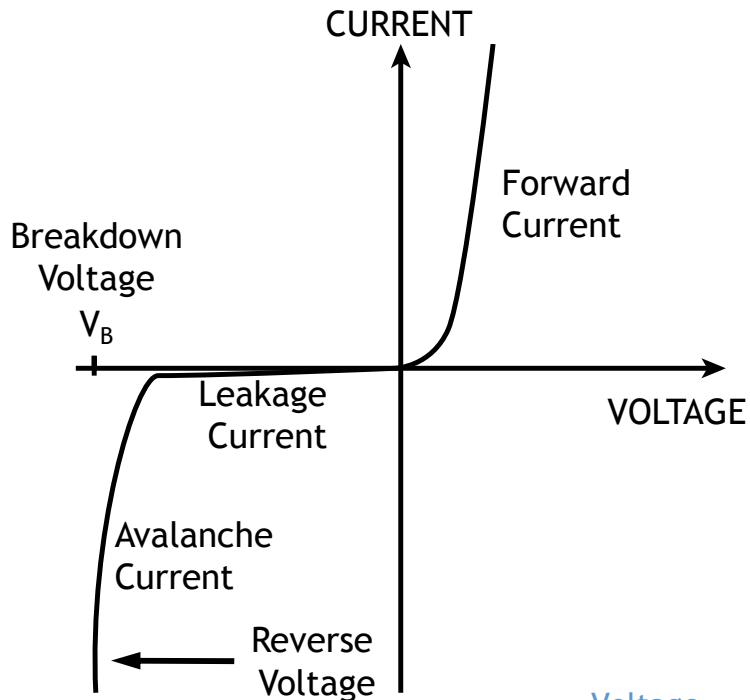
High energy electrons (n-type) fall into low energy holes (p-type)

p-n Junctions and LEDs



p-n Diode





Diode Current

Voltage Across Diode

$$I = I_S \left(e^{\frac{qV_D}{kT}} - 1 \right)$$

Saturation Current in Reverse Bias

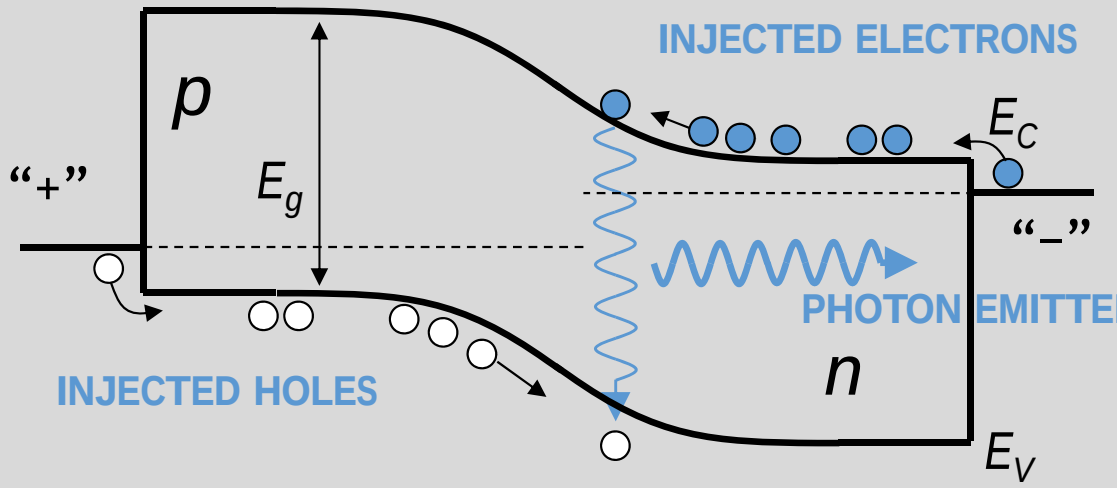
Boltzman Constant

Temperature

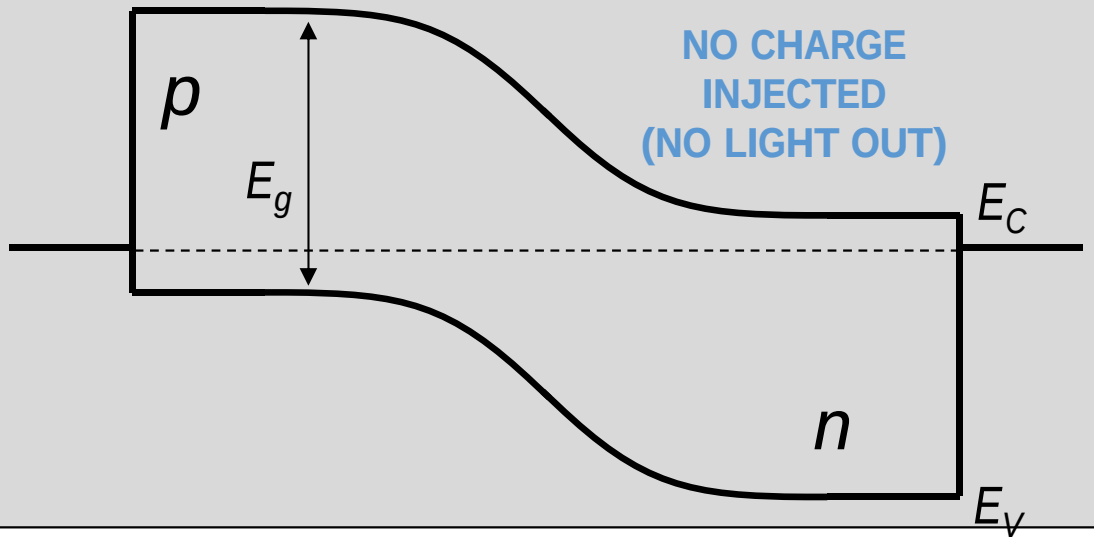
Homojunction p-n Light Emitting Diode

ELECTRICITY IN → LIGHT OUT

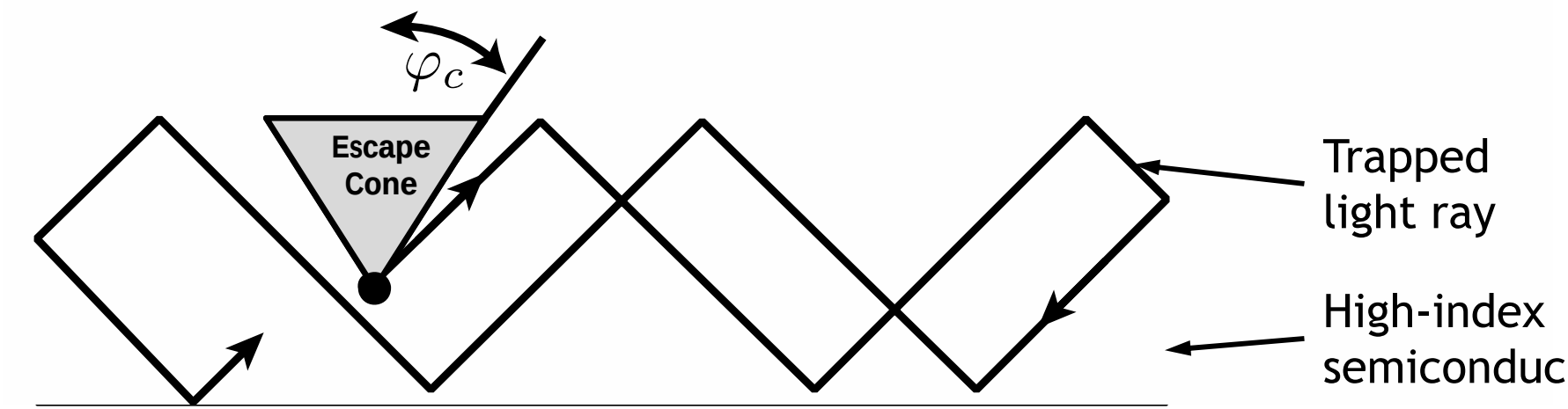
Forward Bias condition



Zero bias condition



Extraction Efficiency of Planar LEDs



$$\frac{P_{escape}}{P_{source}} \approx \frac{1}{2}\left[1-\left(1-\frac{{\phi_c}^2}{2}\right)\right] = \frac{1}{4}\phi_c^2$$

$$\varphi_c = \sin^{-1}\frac{n_2}{n_1}$$

- $\phi_c =$ critical angle of total internal reflection
- Problem: Only small fraction of light can escape from semiconductor.

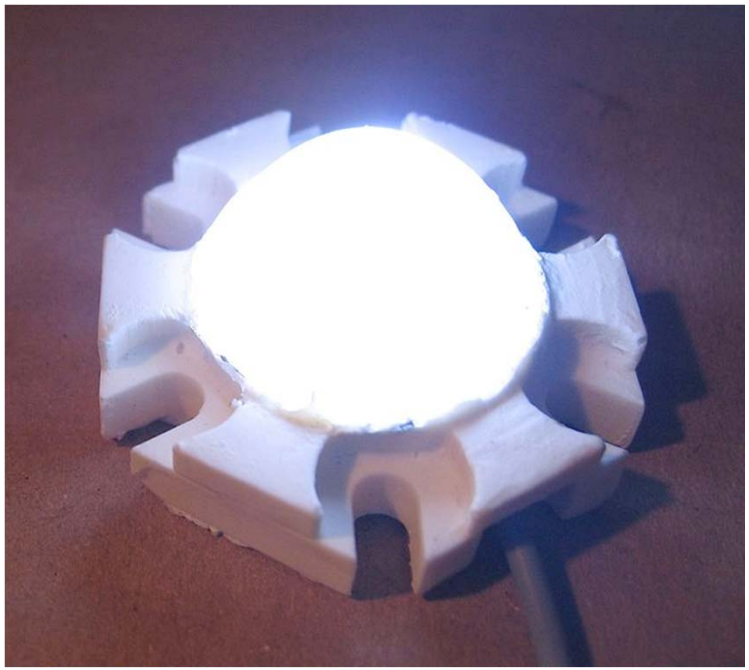
$$\frac{P_{escape}}{P_{source}} = \frac{1}{4}\frac{\vec{n}_{air}}{\vec{n}_s^2}$$

- Above equation gives < 10% extraction efficiency for typical III-V.

Image in the Public Domain

Artificial Lighting consumes 8% of US energy and 22% of US electricity
The energy cost is estimated at $50B annually or $200 per capita

INSTALLED	EFFICIENCY	FRACTION
Incandescent	5%	12%
Fluorescent	20%	62%
HID lamps	25%	26%
White LEDs	35%	----



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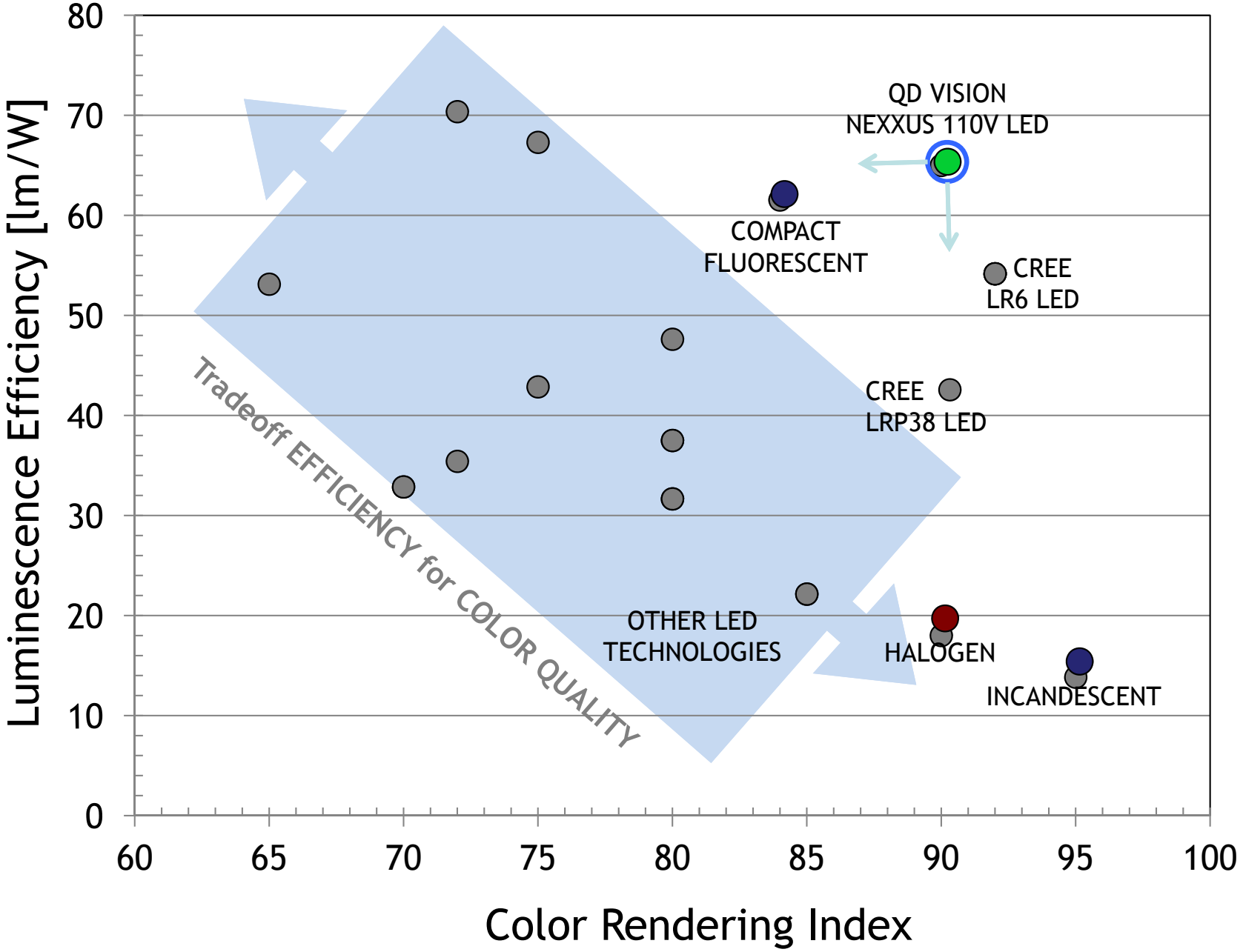
Note: Electric Motor Efficiency is 85%~90%

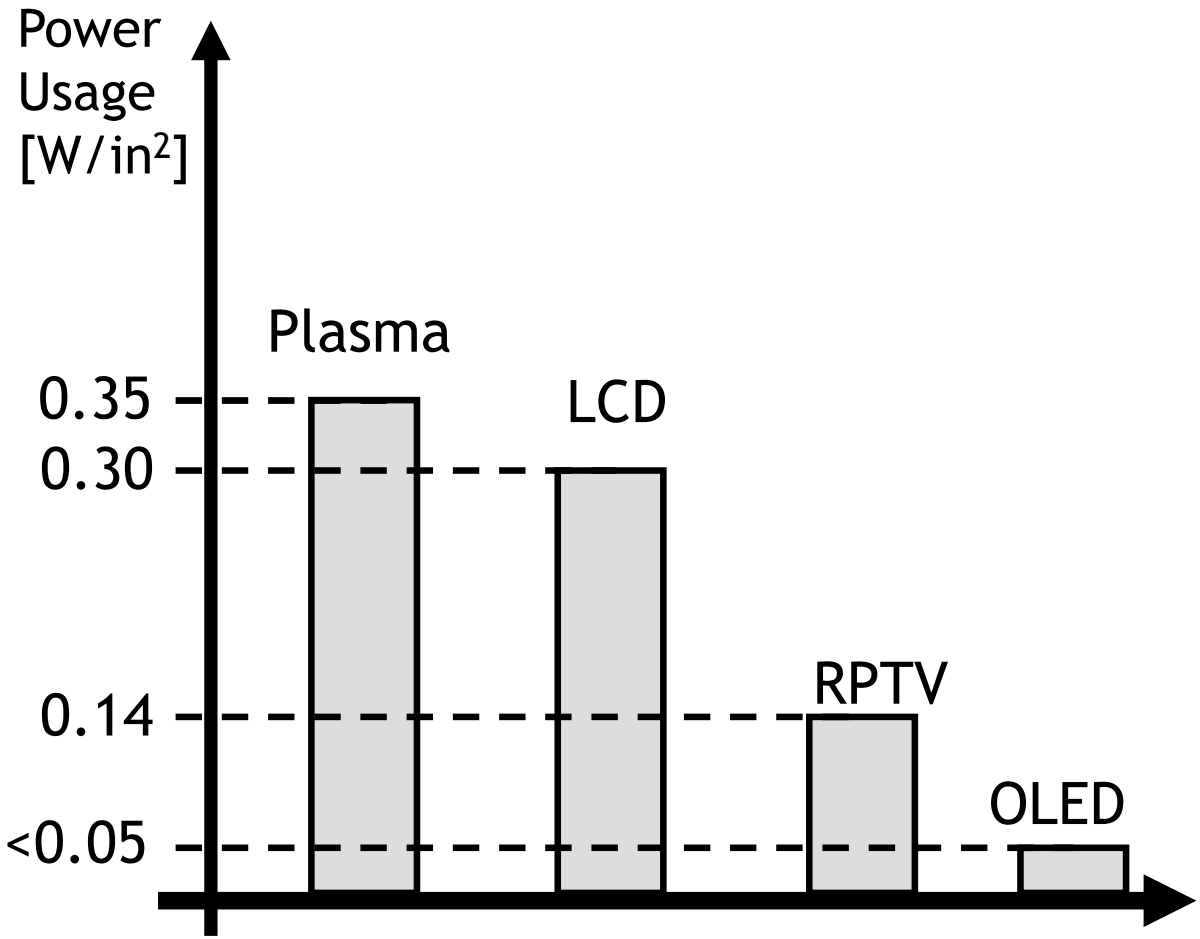
Survey of Lightbulb Technology Performance

(using data from bulbs.com)



OLED: The Green Display

TV and PC Account for 1% each of US Electricity Usage



Plasma, LCD, RPTV power usage values from 2007 CNet report on commercial TV power consumption. OLED value projected from SID 2007 demo. US household power usage data from 2004 report by the Natural Resources Defense Council.

6.007 Electromagnetic Energy: From Motors to Lasers

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