White Light Emitting Diodes

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Energy Law

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Professor Bosselman

Outline

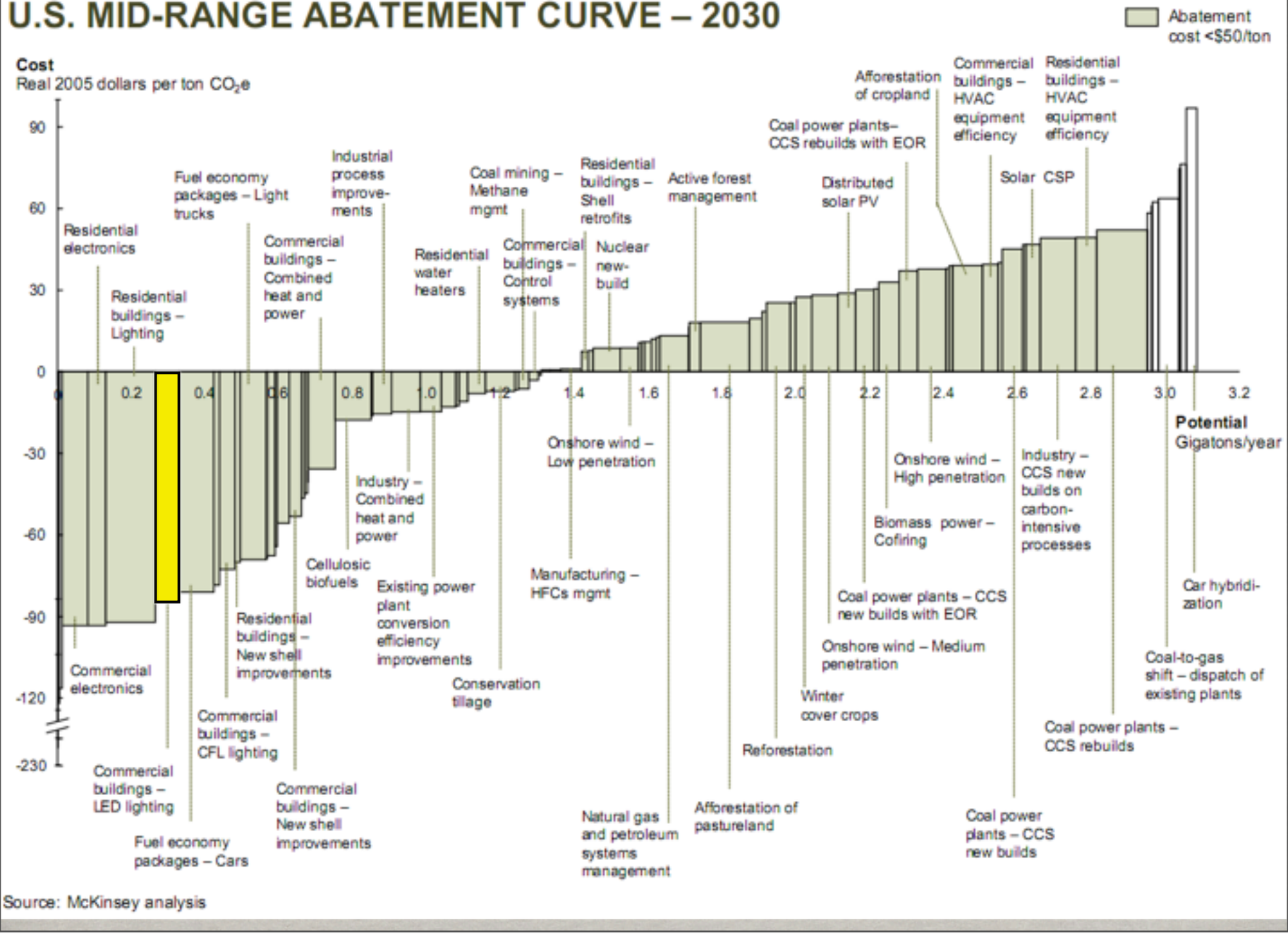
- Lighting Energy Use
- Types of Lighting
- Some Physics
- Generating White Light
- Issues/"Features"

Energy Used for Lighting

- 1/3 of energy is used to generate electricity
- 1/5 of electricity is used for lighting

http://lighting.sandia.gov/XlightingoverviewFAQ.htm#much
http://www.eia.doe.gov/kids/energyfacts/uses/residence.html

U.S. MID-RANGE ABATEMENT CURVE – 2030



Source: McKinsey analysis

Public Policy

• Energy Independence and Security Act goal is to phase out incandescent bulbs in the 40-100 W range

• Replaced by halogen, compact fluorescent, LED lights, or other.

• Recommendation of 45 Lumens/Watt for GP lamps

• Has support of the current administration

BUT some resistance:

• Lightbulb Freedom of Choice Act

• Issues with testing uniformity (CALiPER)

NY Times story on incandescent bulb ban - April 24, 2009
DOE Commercially Available LED Product Evaluation and Reporting program.

Lighting Options

Incandescent

40W
1000 hours

Fluorescent

10W
10,000 hours

LED

1.5W
50,000 hours

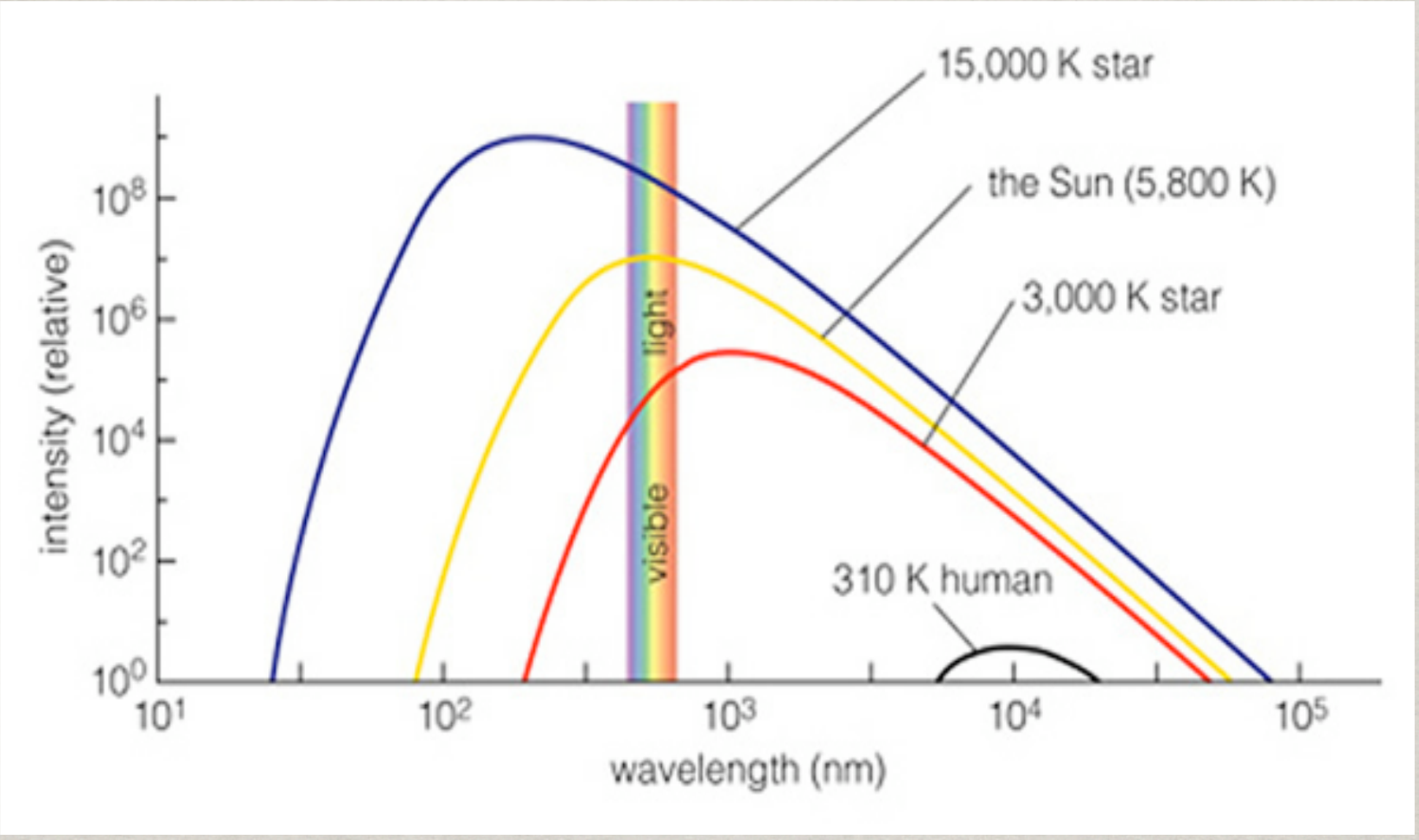
Why the difference?

Bulbs available at local hardware store.

Generation of Light

- Incandescence
- Fluorescence
- Luminescence

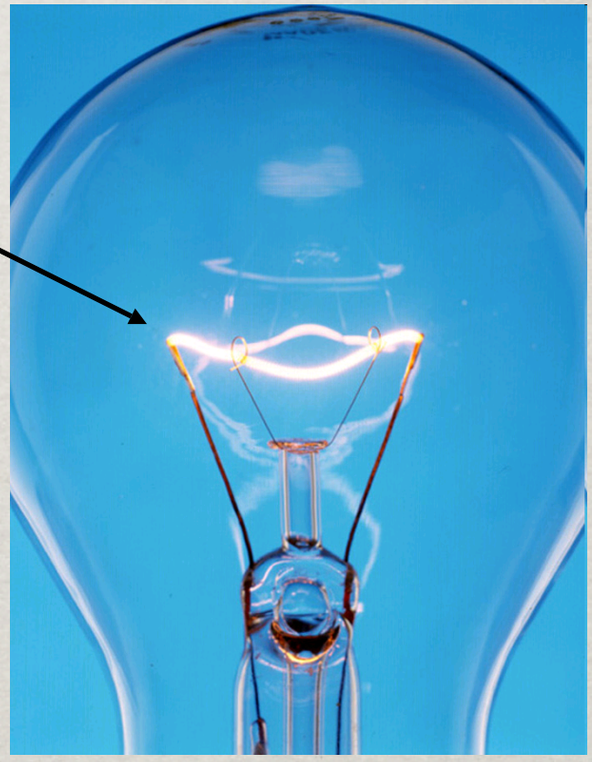
Incandescent Light



http://www.thescienceforum.com/viewtopic.php?p=142514
http://www.ecse.rpi.edu/%7Eschubert/Light-Emitting-Diodes-dot-org/chap18/F18-02%20Planck%20black%20body.jpg

Incandescent Light

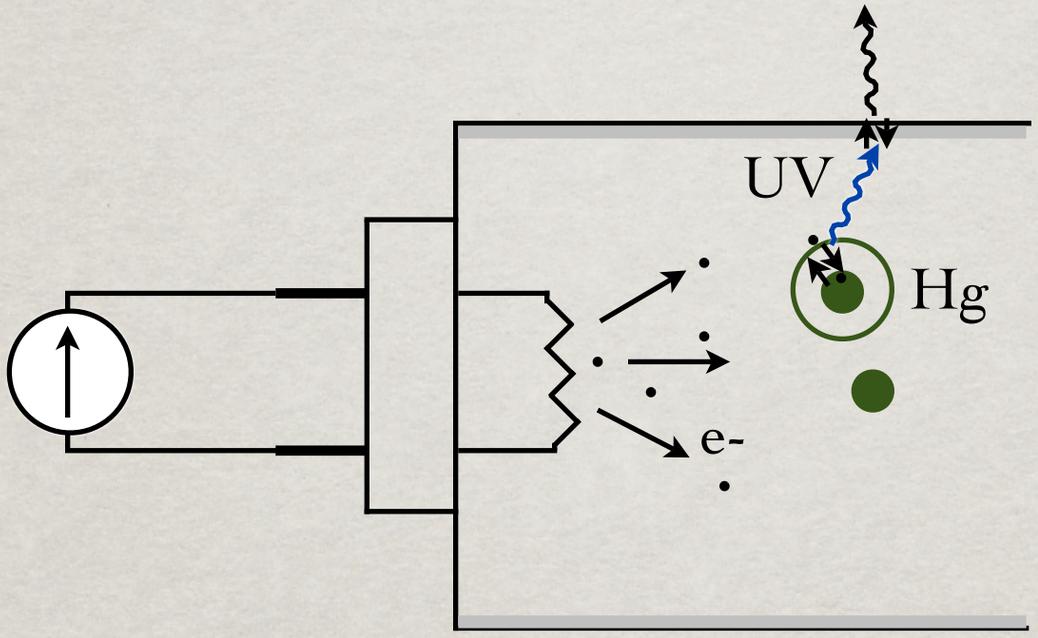
Tungsten Filament
T = 2700-3300 Kelvin



About 95% of the energy supplied to an incandescent bulb is wasted as heat.

Chemistry. Prentice Hall, 1996: 443; "Electric Light." World Book Encyclopedia. World Book, 1998: 174-175; Bloomfield, Louis A. Incandescent Light Bulbs. How Things Work. University of Virginia; "Tungsten." A History of Technology. Oxford, 1958: 98-99; "Incandescent Lamp." Encarta. Microsoft, 1998; http://www.newton.dep.anl.gov/askasci/eng99/eng99569.htm

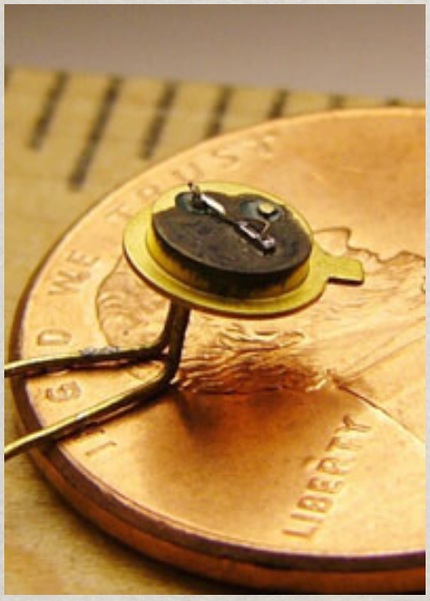
Fluorescent Light



- Inelastic Scattering and Fluorescence
- Hg 
- Switching reduces lifetime
- Inrush at startup

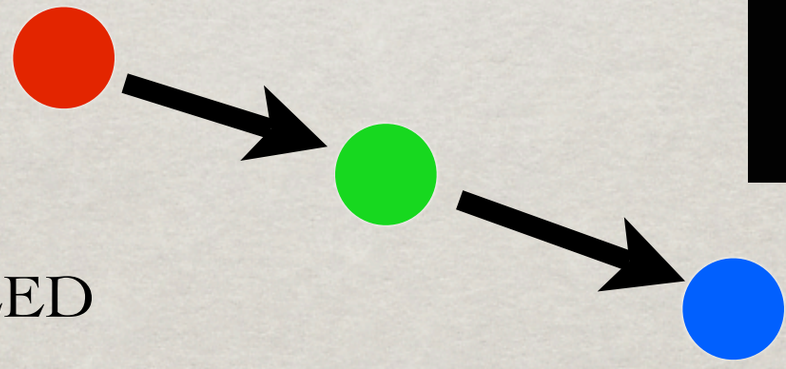
W filament coated with Ba, Sr, Ca oxides.
Ar, Xe, Kr, Ne with low P Hg vapor = 0.3 Atm.
Metallic and rare-earth phosphor salts

History of Light Emitting Diodes



1962 - First visible LED

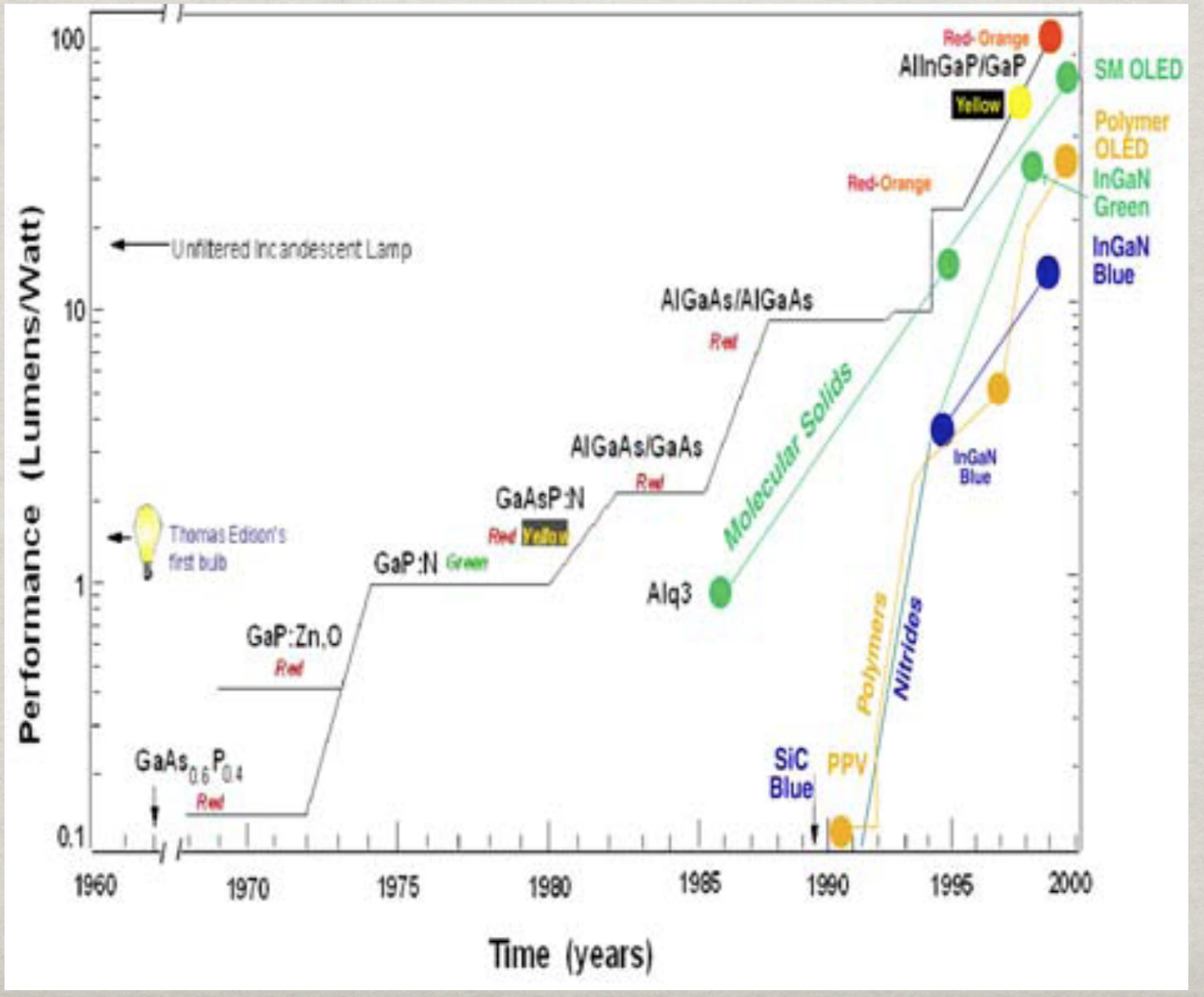
Moved from red to green through the 70's and 80's



1995 - Blue LED

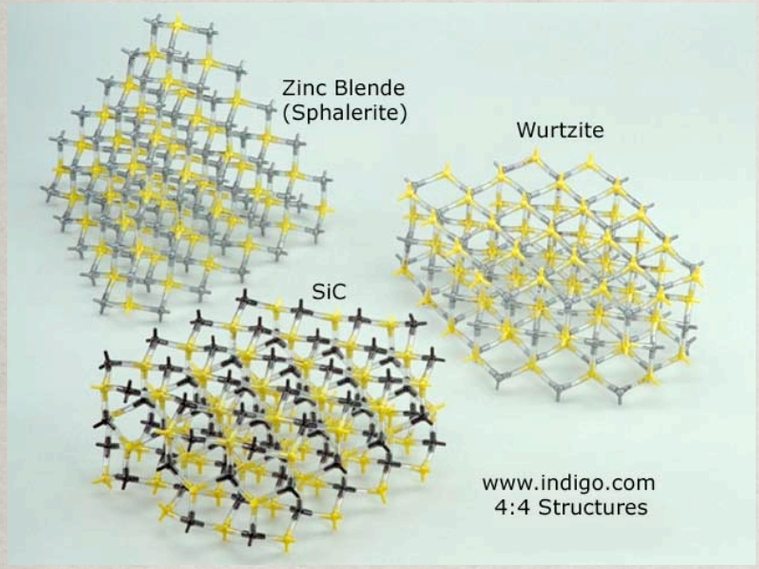
http://bmb.lcd.lu/science/230VAC_LED/index.html
Holonyak diode from www.spectrum.ieee.org/ may04/3986
Nick Holonyak at GE, later U of I
S. Nakamura of Nichia Corporation

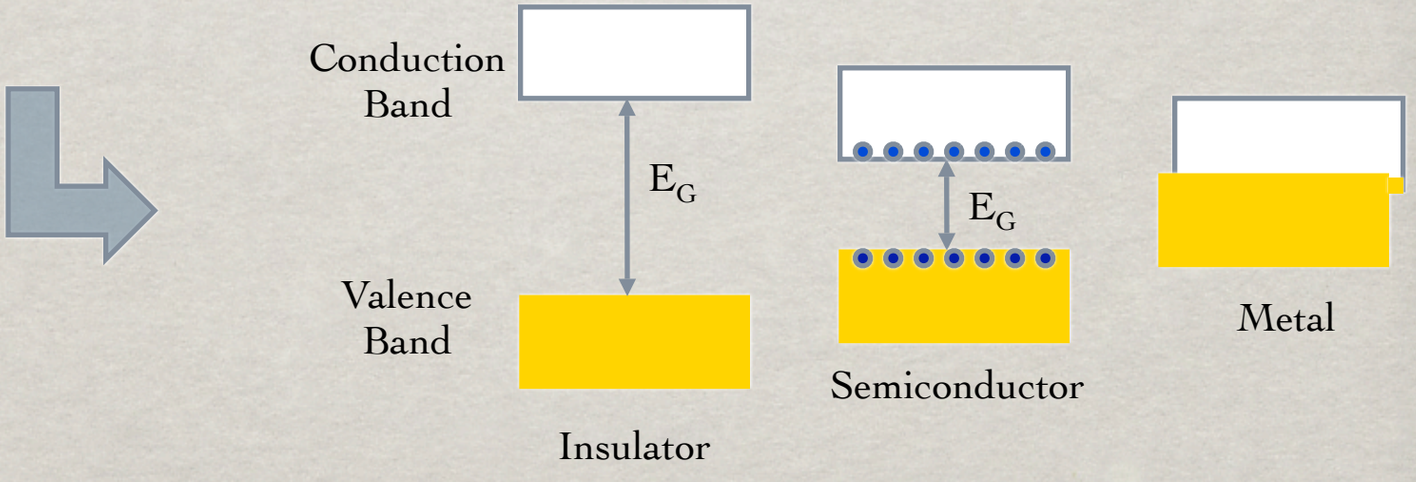
History of LEDs



http://lighting.sandia.gov/lightingdocs/OIDA_SSL_LED_Roadmap_Full.pdf

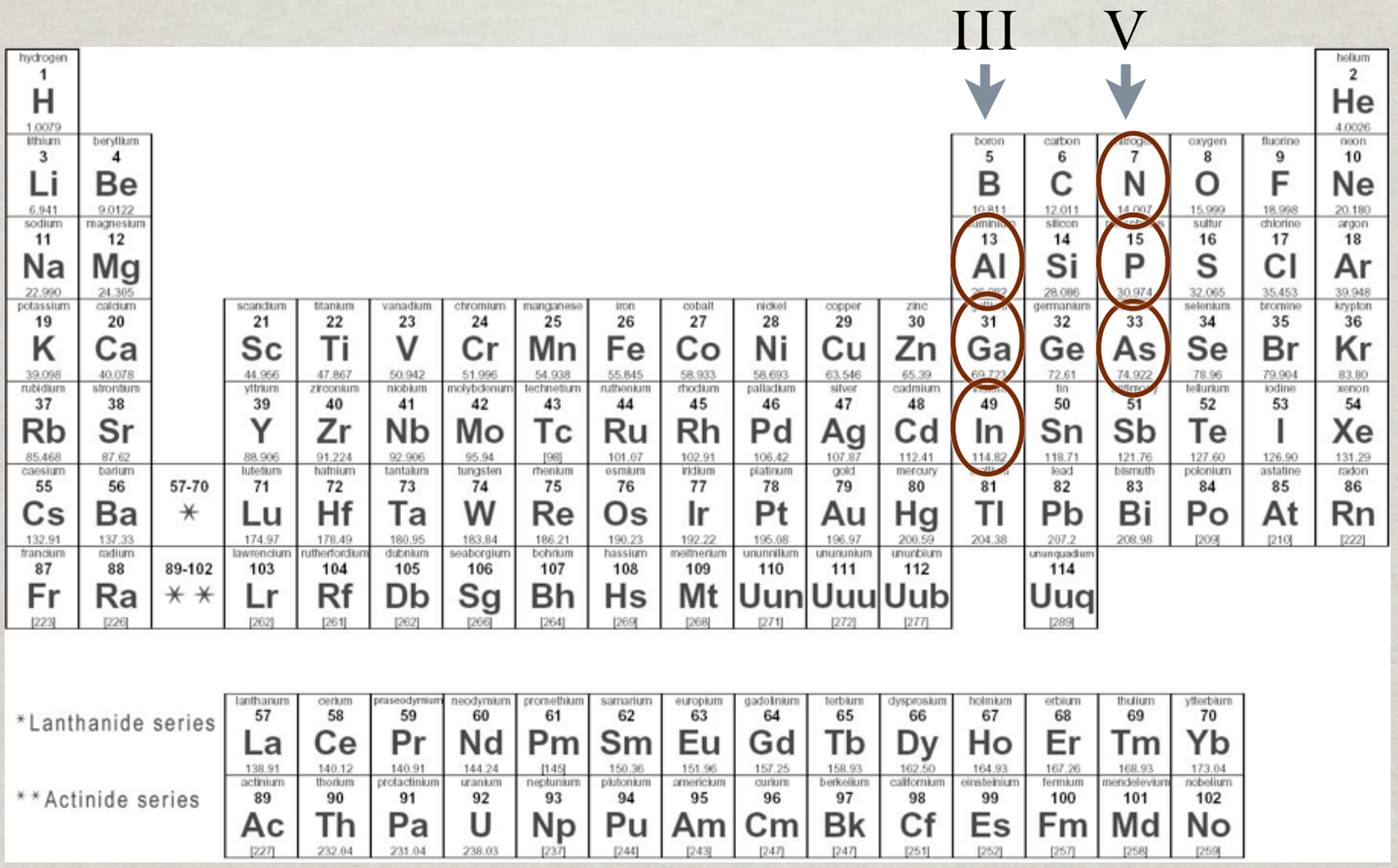
Some Physics of LEDs



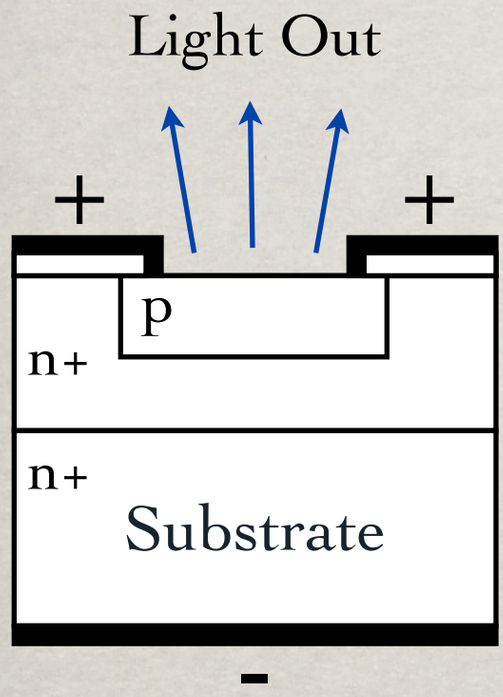


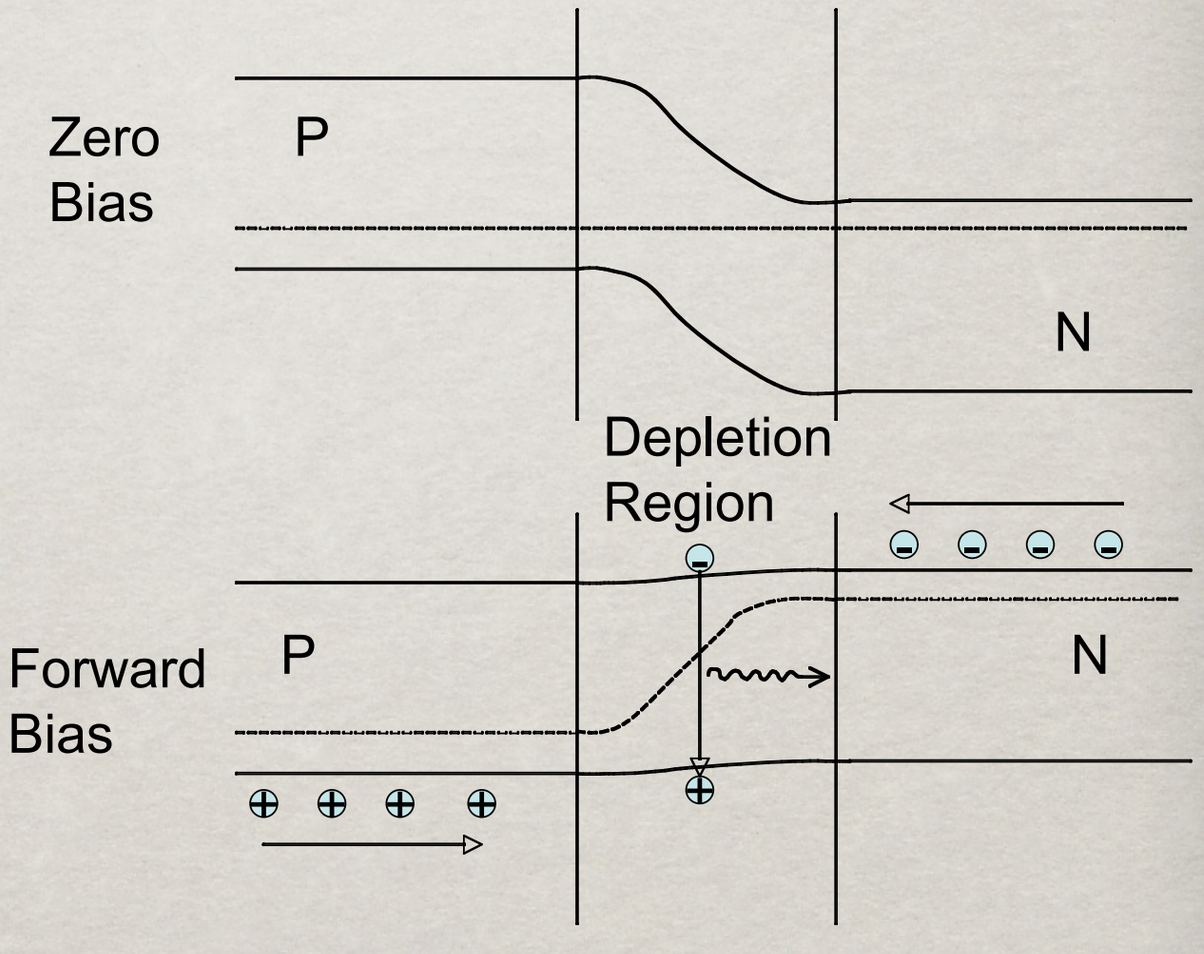
http://www.indigo.com/models/gphmodel/zinc-blende-SiC-wurtzite-model-W.html

Periodic Table of the Elements



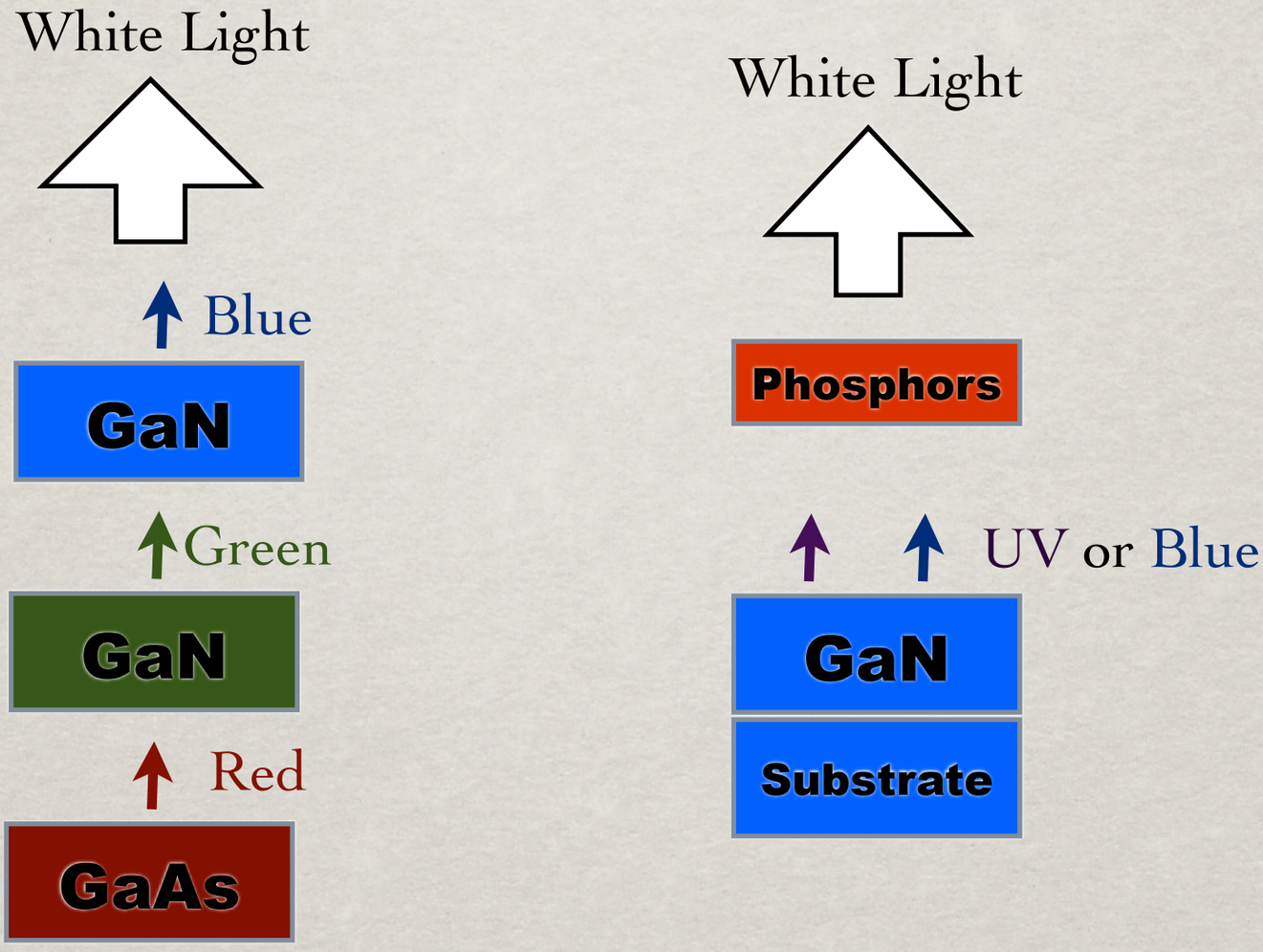
Some Physics of LEDs





Diode created from p-type and n-type semiconductor layers

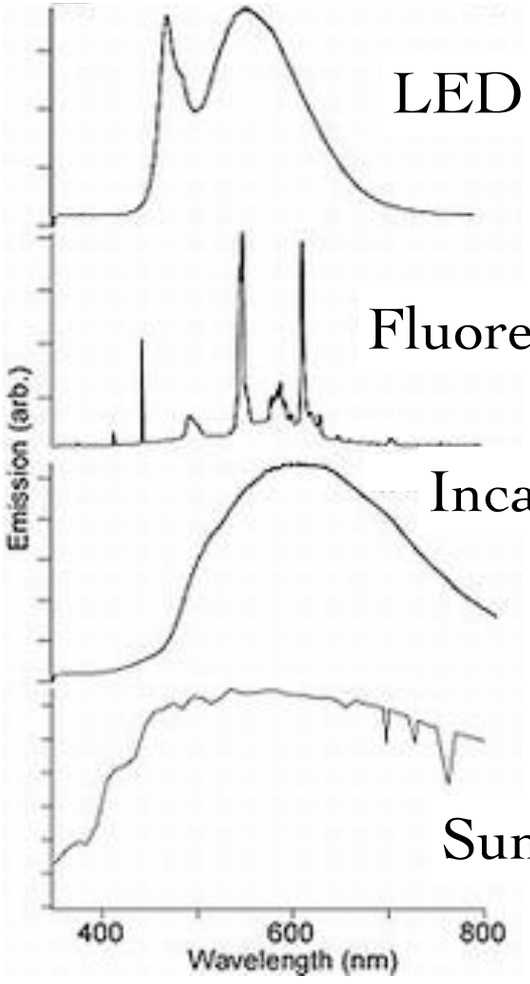
How to Make White Light

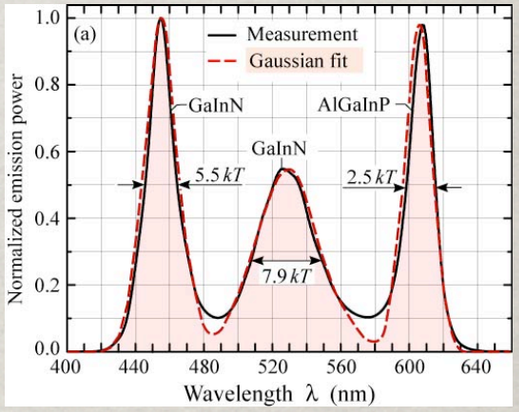


RGB : Pro - color flexibility; Con - temperature variation, control complexity, low CRI

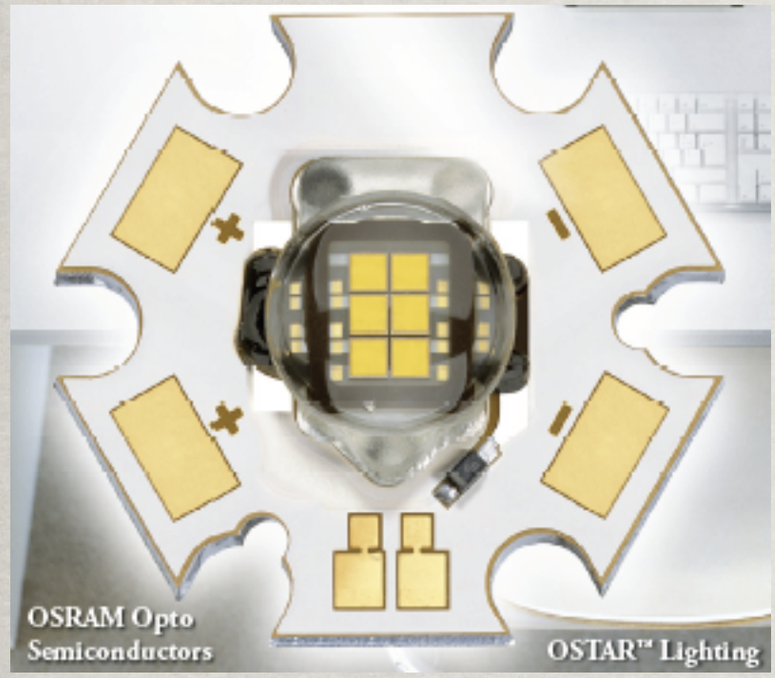
Phosphor: Pro - Mature, high luminous flux, relatively high efficacy, lower cost;
Con High CCT, warmer CCT less available and more costly, color variability in beam.

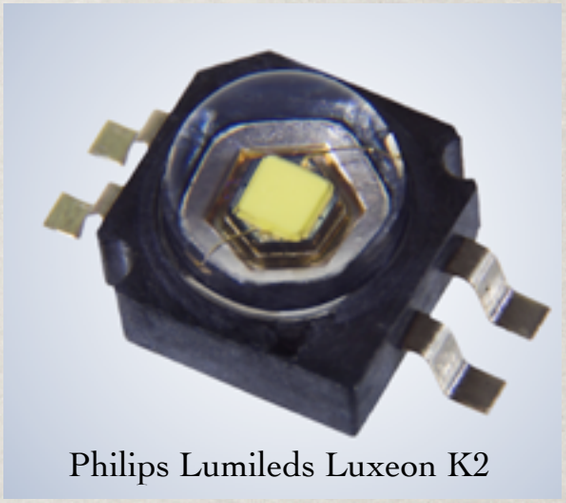
Emission Spectra



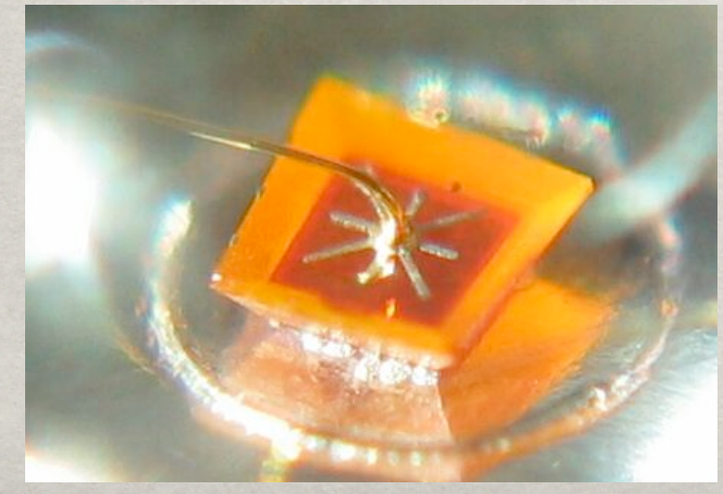


Diode Packaging





Philips Lumileds Luxeon K2



66W Power Consumption
LED Efficacy ≥85 lumens/Watt
Illumination (E): (Height=6m)≥ 27 Lux

"Futuramic thermal dissipation design, got patent."

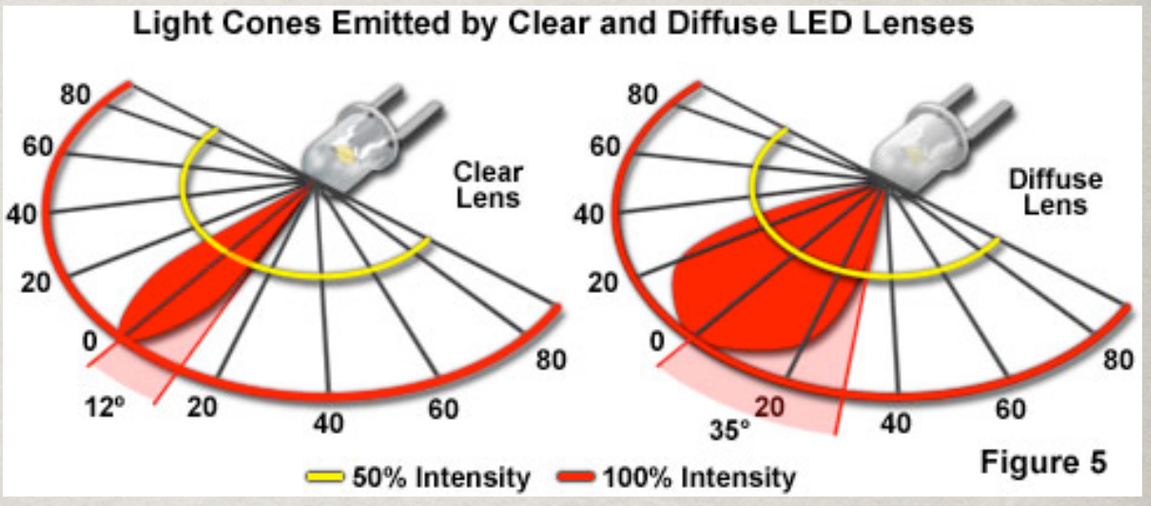
http://www.made-in-china.com/showroom/cnzhled/product-detailqbSmQVFgZuhk/China-LED-Street-Light-ZH-L2W056-.html

Issues/Features

- COST
- Lifetime
- Color
- Efficacy

Why the High Cost?

Diode Beam Shape - Packaging

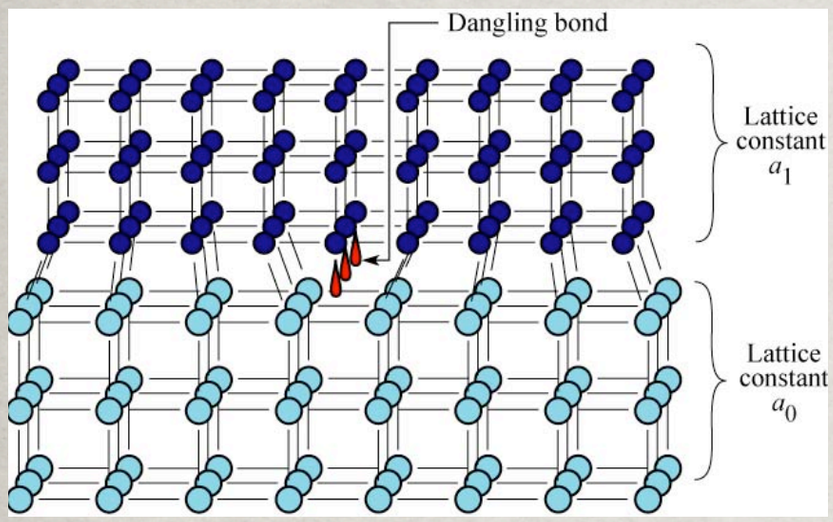


http://micro.magnet.fsu.edu/primer/lightandcolor/ledsintro.html

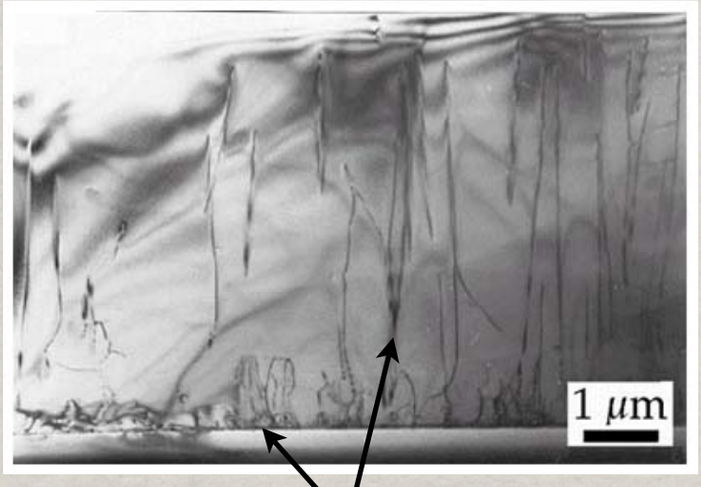
Growth of Semiconductor Materials

- Expensive Processes and Equipment
- Nitrides are difficult to grow
- Substrate Issues

Substrate Issues

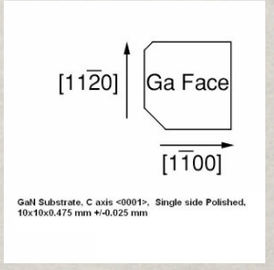


4" Al_2O_3 = $400 2" SiC = $1300



Dislocations

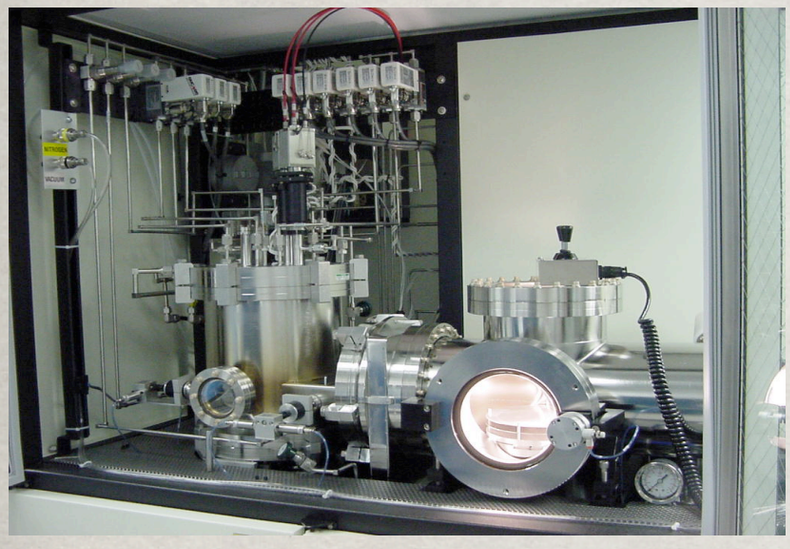
"Super Boule"

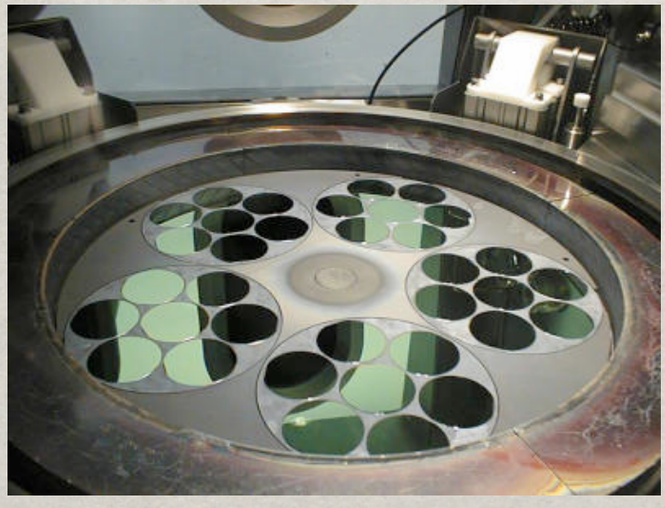


1 cm x 1 cm
GaN = $1300

http://www.ecse.rpi.edu/%7Eschubert/Light-Emitting-Diodes-dot-org/chap07/F07-12%20Dislocations.jpg
GaN on Sapphire - 2" = $500-700 per wafer
Rubicon Sapphire super boule at http://www.ledsmagazine.com/news/6/4/14
Costs from www.mtixtl.com

Growth of Semiconductor Materials

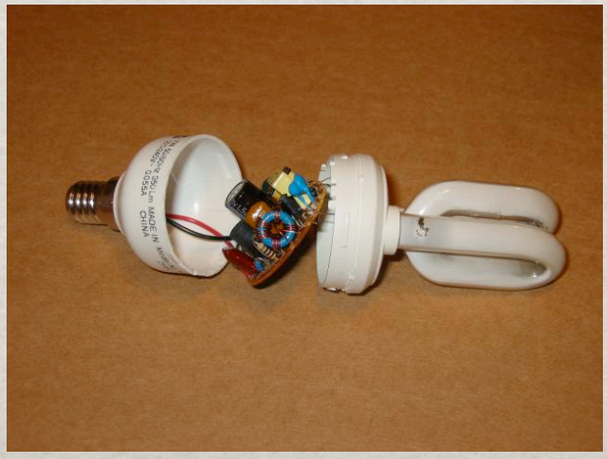




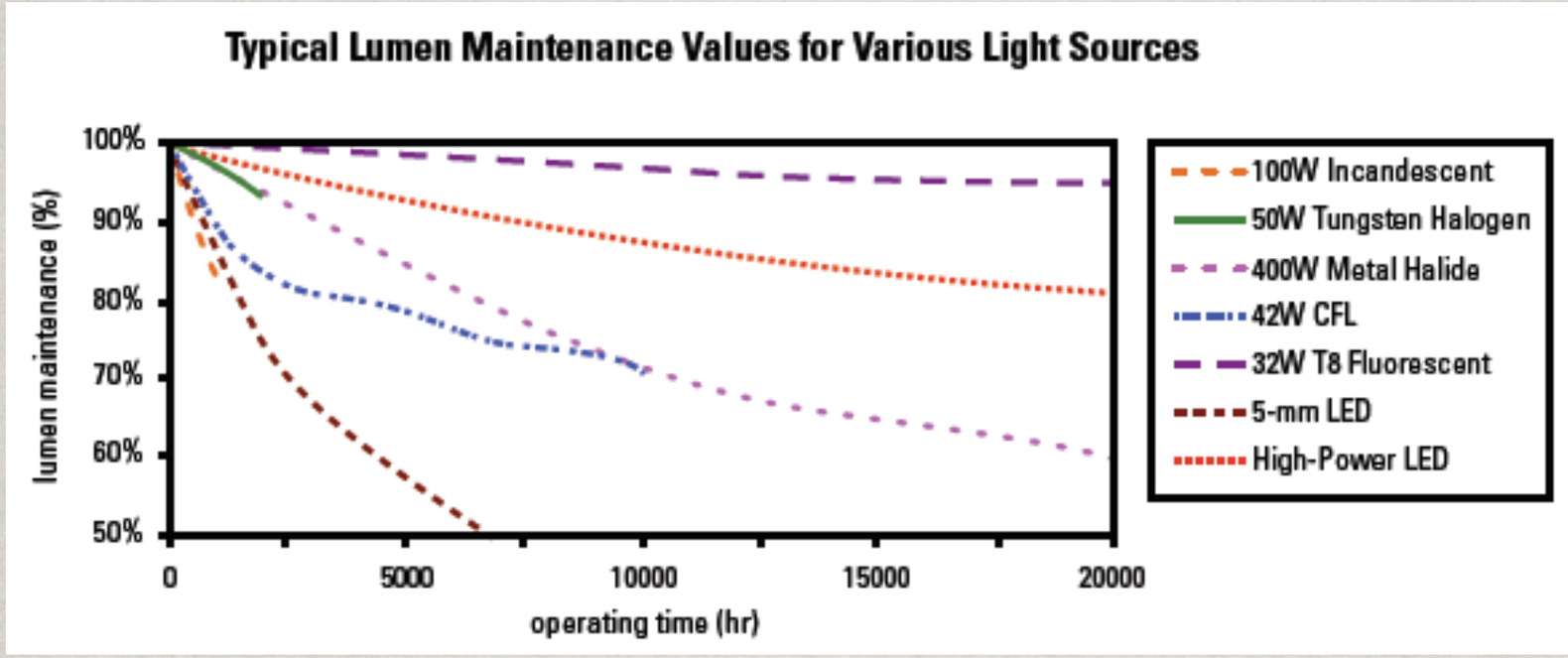
Metal-Organic
Chemical Vapor Deposition

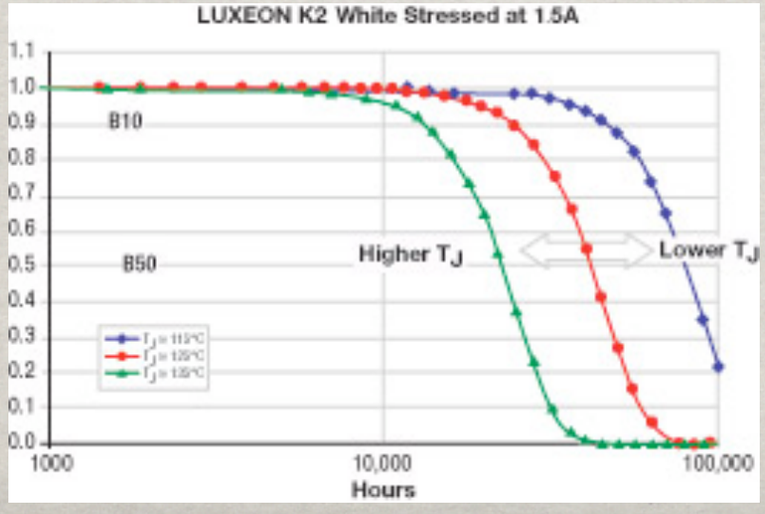
Agere Systems, Alentown, PA and www.aixtron.com

Driver Electronics



Diode Lifetime





Bullough, J.D. 2003, Lighting Answers: LED Lighting Systems. Troy, NY, Lighting Research Center, RPI

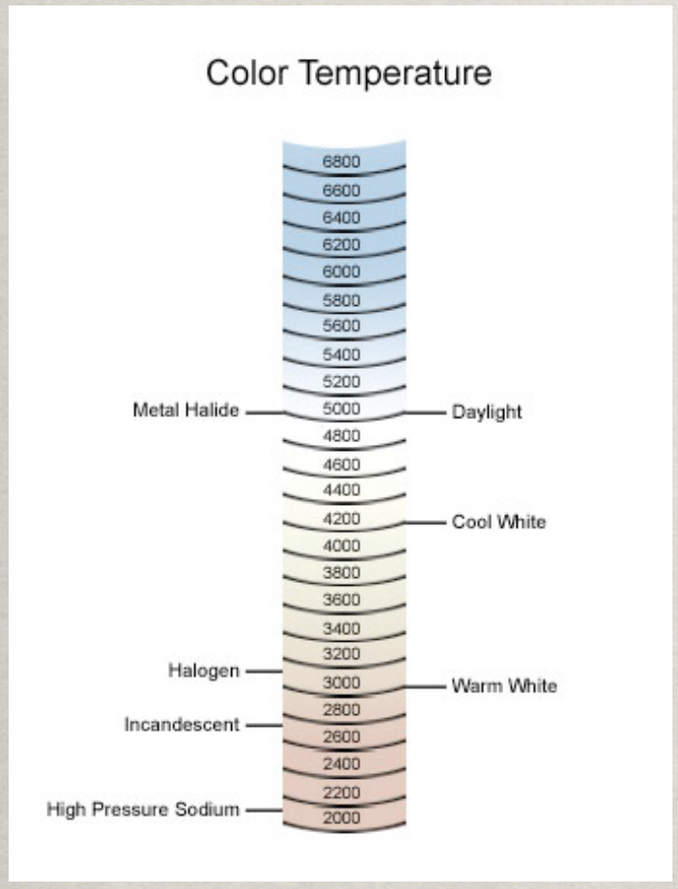
> 70% for general lighting.

50,000 = 5.7 years, so devices are obsolete before they finish life testing.

Estimating ~30,000 hours at I = 350 mA and TJ< 90C.

Switching not relevant to LED lifetime.

Color Temperature



6400K Super Day Light

5000K Day Light

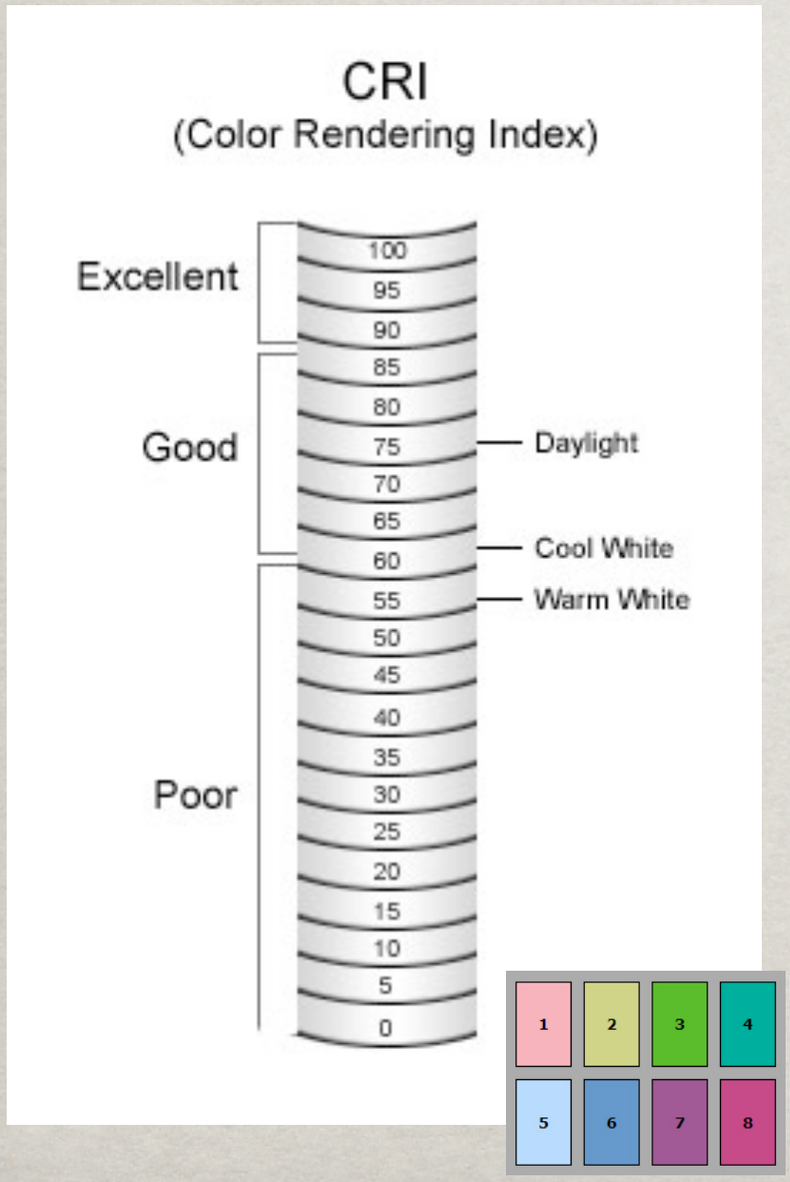
4100K Cool White

2700K Warm White

Correlated Color Temperature from US DOE:
http://www1.eere.energy.gov/buildings/ssl/cct.html

Color temperature is a description of the warmth or coolness of a light source. When a piece of metal is heated, the color of light it emits will change. This color begins as red in appearance and graduates to orange, yellow, white, and then blue-white to deeper colors of blue. The temperature of this metal is a physical measure in degrees Kelvin or absolute temperature. While lamps other than incandescent do not exactly mimic the output of this piece of metal, we utilize the correlated color temperature (or Kelvins) to describe the appearance of that light source as it relates to the appearance of the piece of metal (specifically a black body radiator). By convention, yellow-red colors (like the flames of a fire) are considered warm, and blue-green colors (like light from an overcast sky) are considered cool. Confusingly, higher Kelvin temperatures (3600–5500 K) are what we consider cool and lower color temperatures (2700–3000 K) are considered warm. Cool light is preferred for visual tasks because it produces higher contrast than warm light. Warm light is preferred for living spaces because it is more flattering to skin tones and clothing. A color temperature of 2700–3600 K is generally recommended for most indoor general and task lighting applications. Color Temperature is not an indicator of lamp heat.

Color



Lighting Research Center
Study of lighting preferences

CRI varied from 20-70

Color Rendering Index from USDOE:
http://www1.eere.energy.gov/buildings/ssl/cri.html; and
http://www.lightbulbsdirect.com/page/001/CTGY/CRI

CRI, or Color Rendering Index, is a measurement of a light source's accuracy in rendering different colors when compared to a reference light source with the same correlated color temperature. It generally ranges from 0 for a source like a low-pressure sodium vapor lamp, which is monochromatic, to 100, for a source like an incandescent light bulb, which emits essentially blackbody radiation. The higher the CRI, the better the visual perception of colors. CRI is related to color temperature, in that the CRI measures for a pair of light sources can only be compared if they have the same color temperature (see Color Temperature Chart).

The highest attainable CRI is 100. Lamps with CRIs above 70 are typically used in office and living environments. A standard "cool white" fluorescent lamp will have a CRI near 62.

http://www.lrc.rpi.edu/programs/solidstate/cr_LEDReadingLights.asp

Efficacy (Light Output per Power Input)

Source	Luminous Efficacy (lm/W)
Incandescent	10-18
Halogen	15-20
Compact Fluorescent	35-60
Linear Fluorescent	50-100
Metal Halide	50-90
Cool White LED	47-64
Warm White LED	25-44

Recent LED results of 130 lm/W @ 5800K and 100 lm/W @ 2950K
Roadmaps predict up to 200 lm/W for LEDs

http://www1.eere.energy.gov/buildings/ssl/efficacy.html

Includes ballast or driver for fluorescents and LEDs (15%)

Organic LEDs

http://www.printedelectronicsworld.com/articles/europe_joins_r_amp_d_forces_on_organic_led_technology_00000150.asp?sessionid=1
http://www.ledsmagazine.com/news/6/4/13

Some Holdouts?