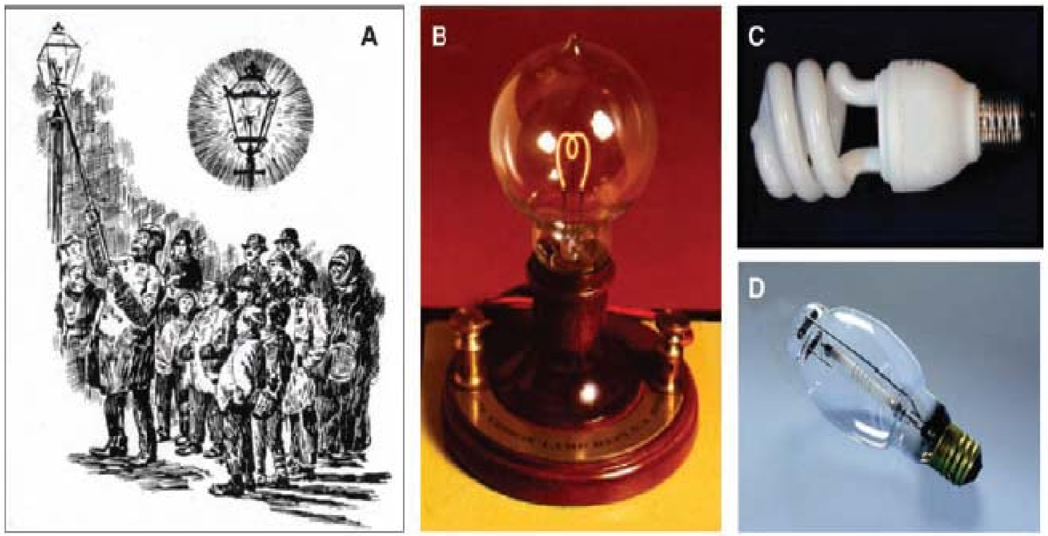
Light Emitting Diode (LED)

Shengyao Li

History of Light Bulbs



(A) 1880s illustration of the nightly Illumination of a gaslight with a thorium oxide-soaked mantle.
(B) Replica of Edison's lamp.
(C) Contemporary compact fluorescent lamp.
(D) High-pressure sodium lamp.

Facts about incandescent light bulbs:

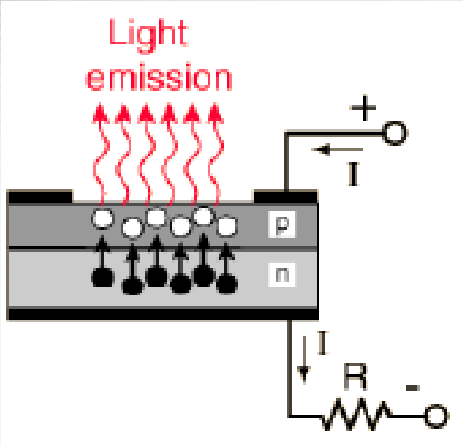
- **Low energy efficiency**
- **Limited color choice**
- **Short useful lifetime**

Facts about fluorescent lamp:

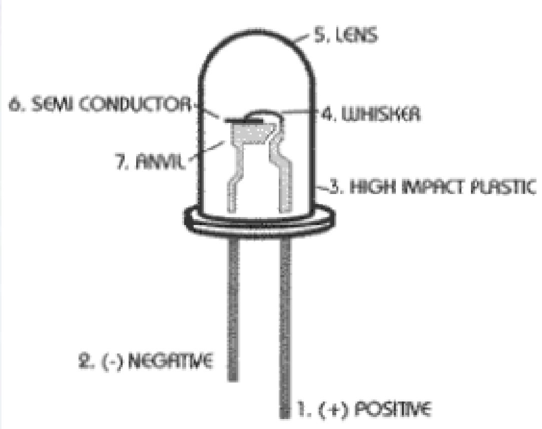
- **Better energy efficiency**
- **Uniformity of white light**
- **Mostly mercury based**
- **Recycling issues**

E. Fred Schubert and Jong Kyu Kim, *Science* **308**, 1274 (2005).

Brand New Quantum Devices - LED



LED Chip



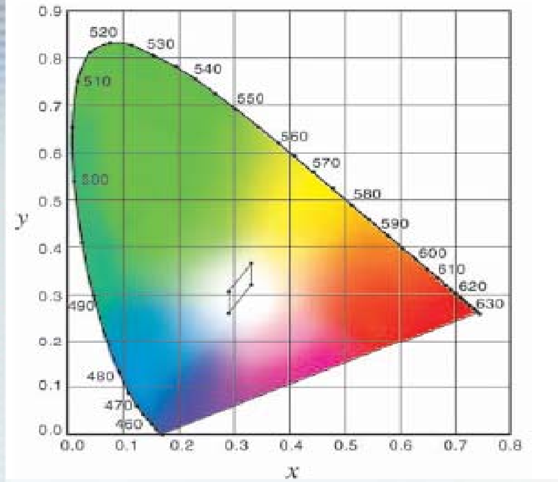
LED Package

Mechanism

- Basic semiconductor device
- Converts electric energy into light
- Composed of N-type & P-type regions
- Electron hole combination emits light
- Semiconductor materials dictate the emitted photonic frequency and efficiency
- Different materials produce different color of light

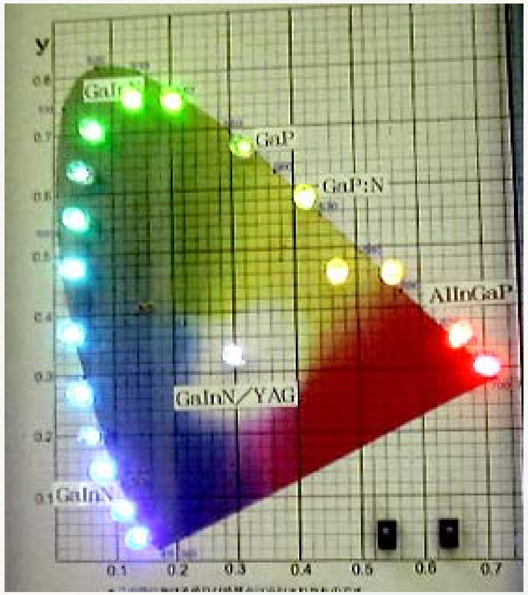
HyperPhysics (©C.R. Nave), Light Emitting Diode Structure, Available at http://hyperphysics.phy-astr.gsu.edu/hbase/electronic/led.html, (2006).
The LED Light.com, Application Notes, Available at http://www.theledlight.com, (2007).

Light Colors and Corresponding Materials



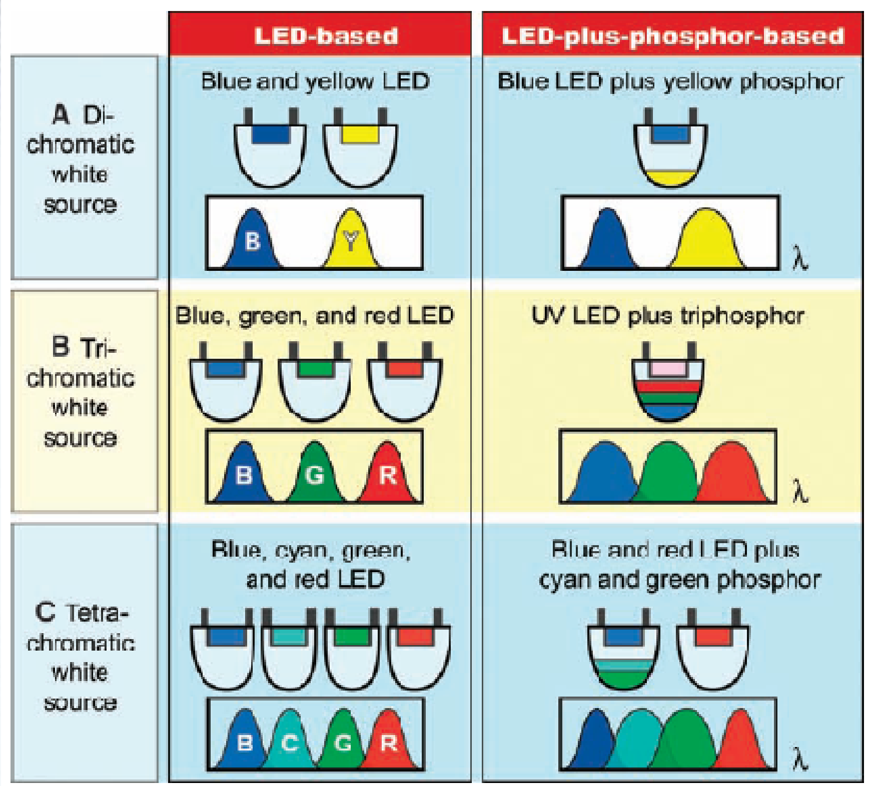
Comparison of chip technologies for wide angle, non-diffused LEDs

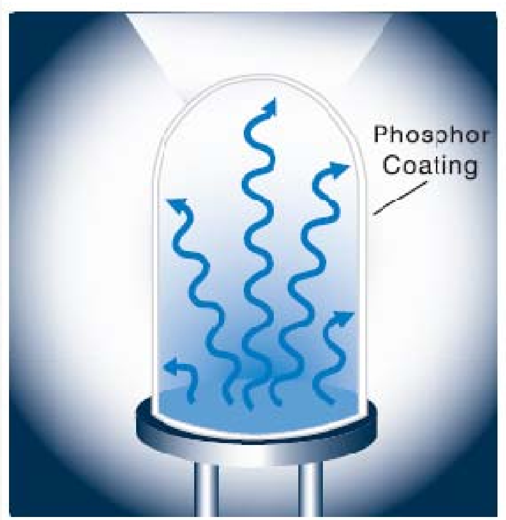
LED Color	STANDARD INTENSITY: Chip Material	STANDARD INTENSITY: λpk (nm)	STANDARD INTENSITY: Iv(mcd) @ 20mA	HIGH INTENSITY: Chip Material	HIGH INTENSITY: λpk (nm)	HIGH INTENSITY: Iv(mcd) @ 20mA
Red	GaAsP/GaP	635	120	AlInGaP	634	5,300
Orange	—	—	—	AlInGaP	605	2,000
Amber	GaAsP/GaP	583	100	AlInGaP	592	5,300
Green	GaP	565	80	InGaN	520	2,400
Blue	—	—	—	InGaN	465	700
Cool White	—	—	—	InGaN	5,500 k	1,560
Warm White	—	—	—	InGan	3,300 k	1,800



Data Display Products, in *Solid-State Lighting Catalog* (2005).
NIST Physics Laboratory, OPTICAL TECHNOLOGY DIVISION, Available at http://physics.nist.gov/TechAct.99/Div844/div844h.html, (1999).

Current Area of Interests – White LEDs





Common phosphor material:

Cesium-doped yttrium-aluminum-garnet (YAG)

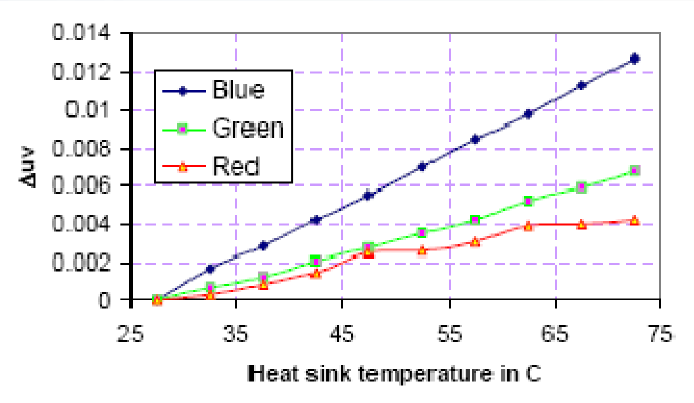
- Color rendering index (CRI) value – the color difference between measured color and reference color based on blackbody radiation
- High CRI value reflects "true color"
- Tradeoff between luminous efficiency and color rendering for LEDs
- Dichromatic white LEDs: Best luminous efficiency (425 lm/W) + lowest color rendering capability.
- Tetrachromatic white LEDs: Excellent color rendering capability + poor luminous efficiency.
- Trichromatic white LEDs are in between with ~300 lm/W

Data Display Products, in *Solid-State Lighting Catalog* (2005).

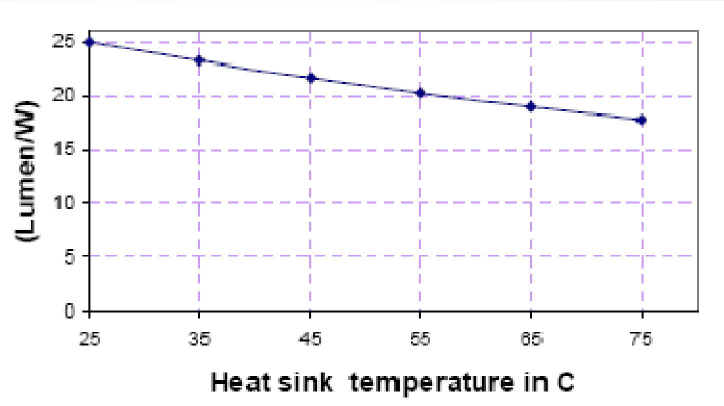
E. Fred Schubert and Jong Kyu Kim, *Science* **308**, 1274 (2005).

LEDs' Color Stability

Failure Analysis of White LEDs

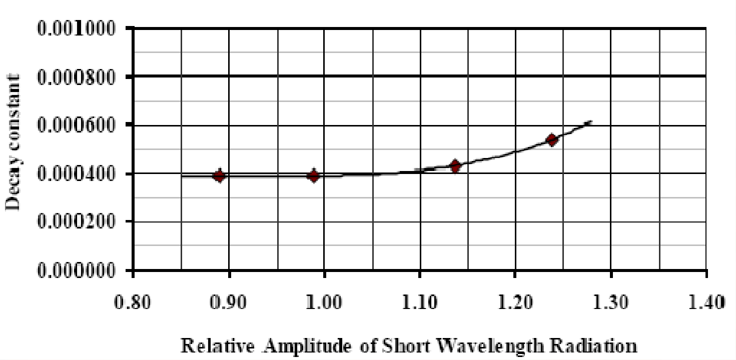


minimum-perceptible-color-difference variation in red(610 nm), green(540 nm), blue(470 nm) LEDs with respect to temperature

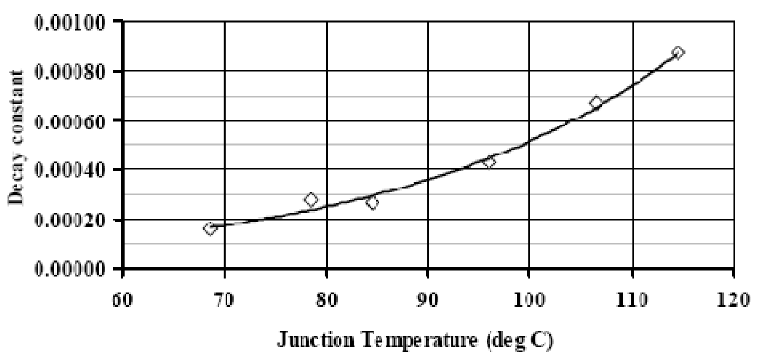


Degradation of luminous efficiency with increasing temperatures

Phosphor Based White LEDs' Color Stability



LEDs' decay constant as a function of short wavelength radiation



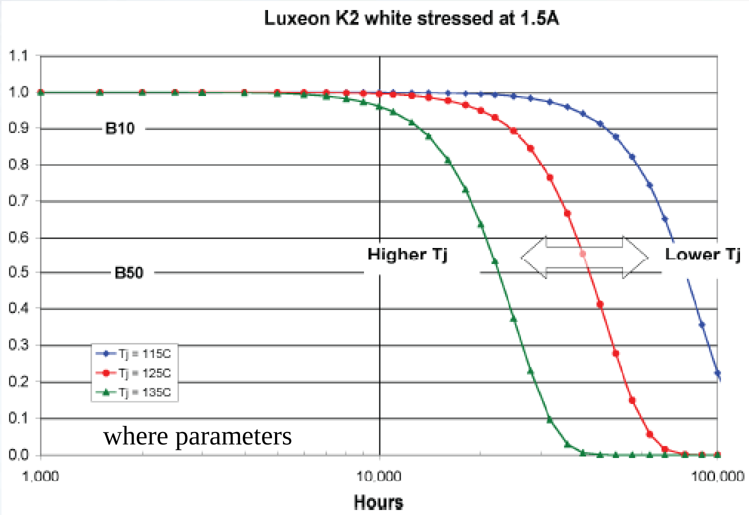
LEDs' decay constant as a function of junction temperature

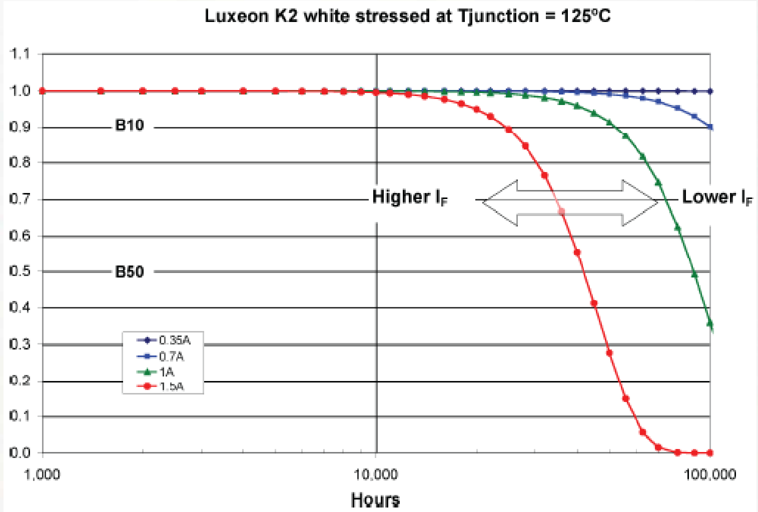
Subramanian Muthu, Frank J. Schuurmans, and Michael D. Pashley, *IEEE journal on selected topics in quantum electrons* (2002).

N. Narendran, Y. Gu, J. P. Freyssinier et al., Rensselaer Polutechnic Institute, 2004.

LEDs' Useful Lifetime

Philips Lumileds Luxeon K2

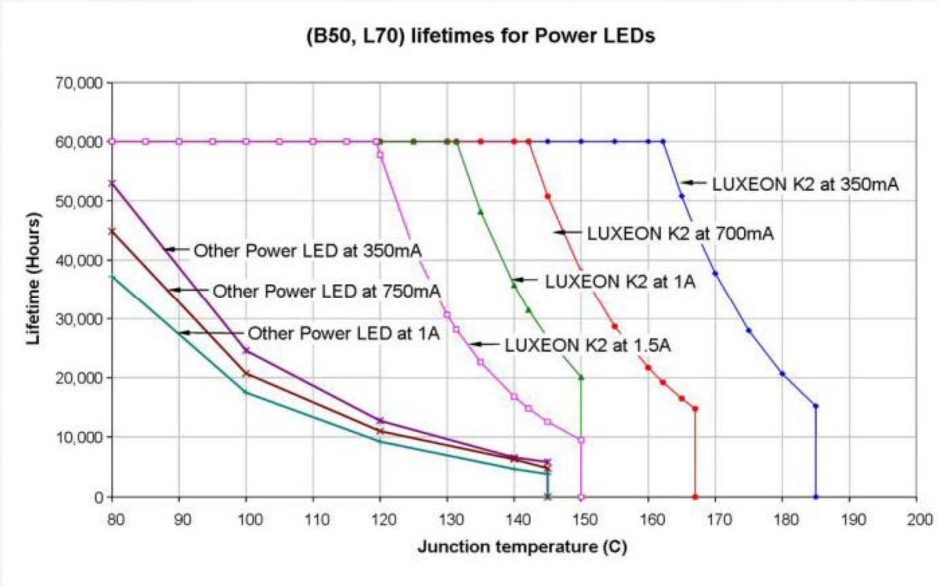




LEDs' lifetime data which Lumileds uses are generated by the Weibull distribution function

$$f(t) = \frac{\beta}{\alpha} \cdot \left(\frac{t}{\alpha} \right) \cdot e^{-(\frac{t}{\alpha})^{\beta}}$$

where parameters α, β are determined by experimental data, and the Weibull distribution function is then used to extrapolate the useful lifetime of test LED



Philips Lumileds, in *Technology White Paper* (2007), pp. 1.

Application 1 - Mobile Appliances

Market share peaked at 57% of the entire LED market in 2004, 48% in 2006

Reasons:

- Growing global manufacturing competition drives down the profit.
- Alternative technology such as organic light emitting diode

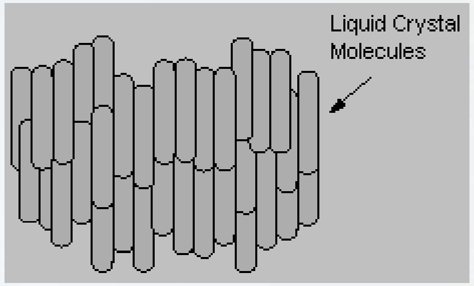
several components of a mobile handset that demand for the use of LEDs

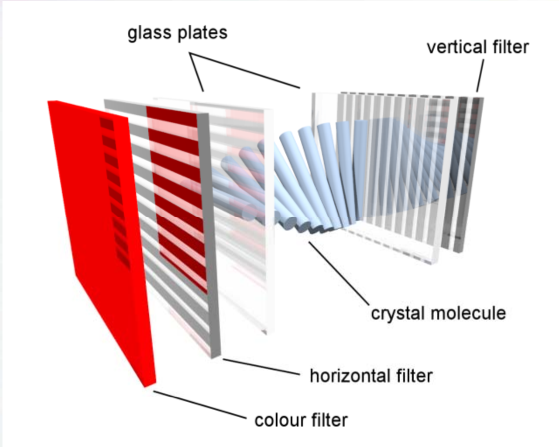
Tim Whitaker, in *LEDs Magazine* (2006), pp. 9.

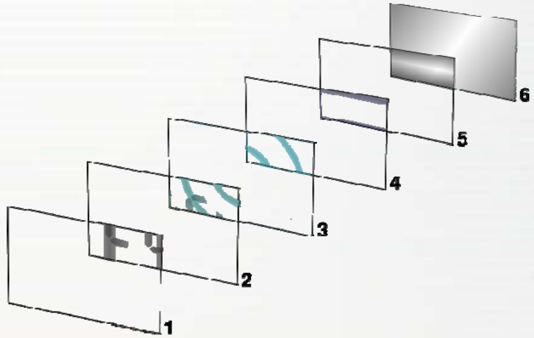
Components with LED usage

LCD Screens

Material: twisted nematic







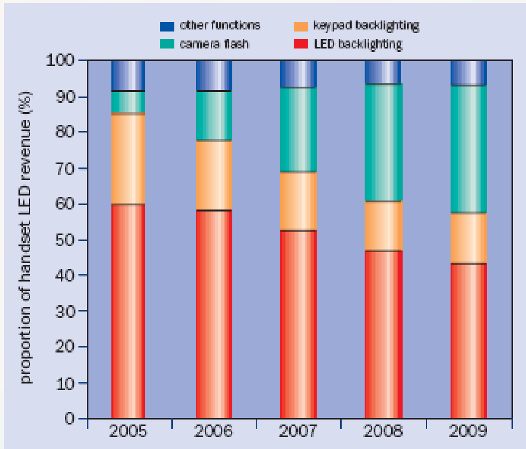
LED Backlight offers:

- Extreme long life
- Immunity to vibration
- Low cost
- Low operating voltage
- Precise control over light intensity

Keypad

LED offers dynamic light color shift and intensity change

Sony Ericsson's K750i is quipped with 2Mpixel camera and two high-power LEDs as camera flash



Camera Flash

LED camera flash: NO have charge time.

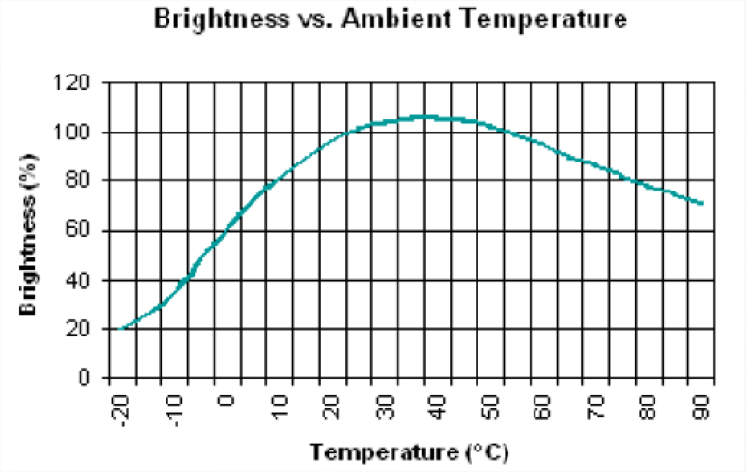
This component of mobile handsets has great market potential of adapting high intensity white LEDs.

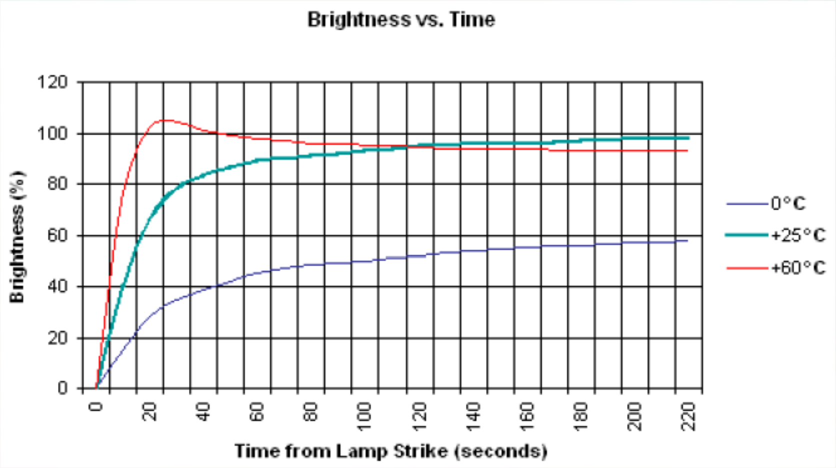
Application 2 - Large LCD Display

Traditional backlight: cold cathode fluorescent lamp (CCFL)

Problems:

- CCFLs' brightness has temperature dependence, and they do not work well in the low temperature range.
- CCFLs need time to warm up, so there is a significant color variance over time.
- CCFLs only perform well at high frequency sinusoidal current (~35 KHz)





LED solves all these problems, and LED backlit LCD TVs are already commercially available.

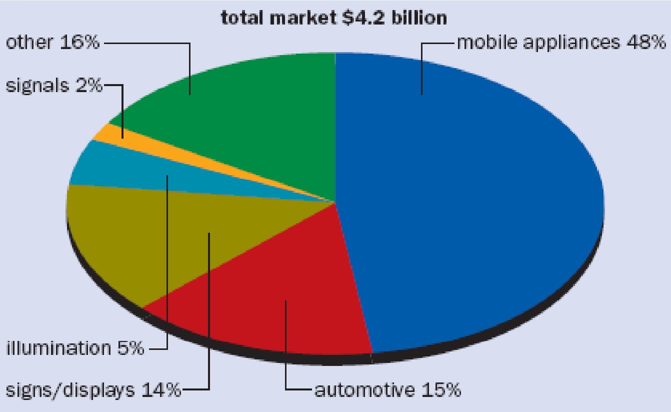
Samsung's first LCD TV based on LED backlighting technology LE40M91

Tokyo JVC's LED backlit LCD TV at CEATEC 2006

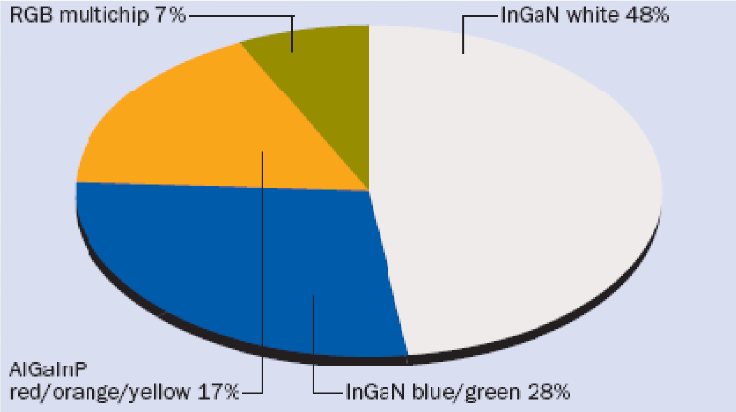
Maxim Integrated Products, CCFL Characteristics, Available at http://www.maxim-ic.com/appnotes.cfm/an_pk/3528, (2007).

Market Overview

Two Market Trends



High intensity LED market by application in 2006



High intensity LED market by color in 2006

The market share for the illumination is expected to grow over $1 billion by 2011.

In fact, high intensity white LEDs have already started to dominated the entire LED market.

With a more developed technology , high intensity white LEDs have been used in very general applications such as streetlights in Canada.

Tim Whitaker, in *LED Suppliers Directory* (2007), pp. 5.

LEDs Magazine, in *LEDs Magazine* (2007), pp. 18.

Conclusion

- Very mature technology
- Highly applicable
- Exploring new area of manipulating light
- Stage of design and package optimization
- Bright future & profound impact on society
- Solving the energy shortage problem by more effective electricity usage

? Questions ?

"I'm trying to turn gold into silicon chips."