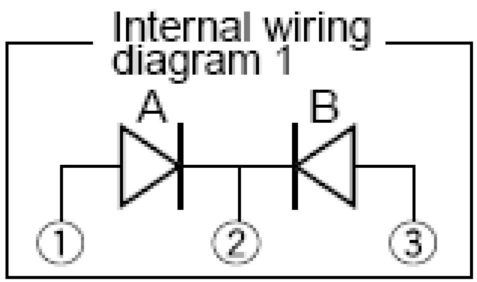
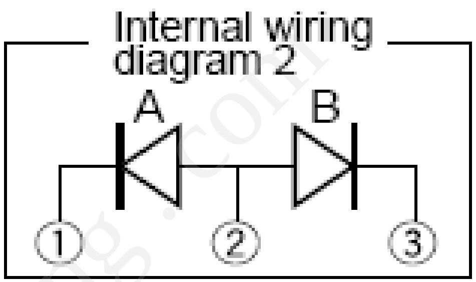
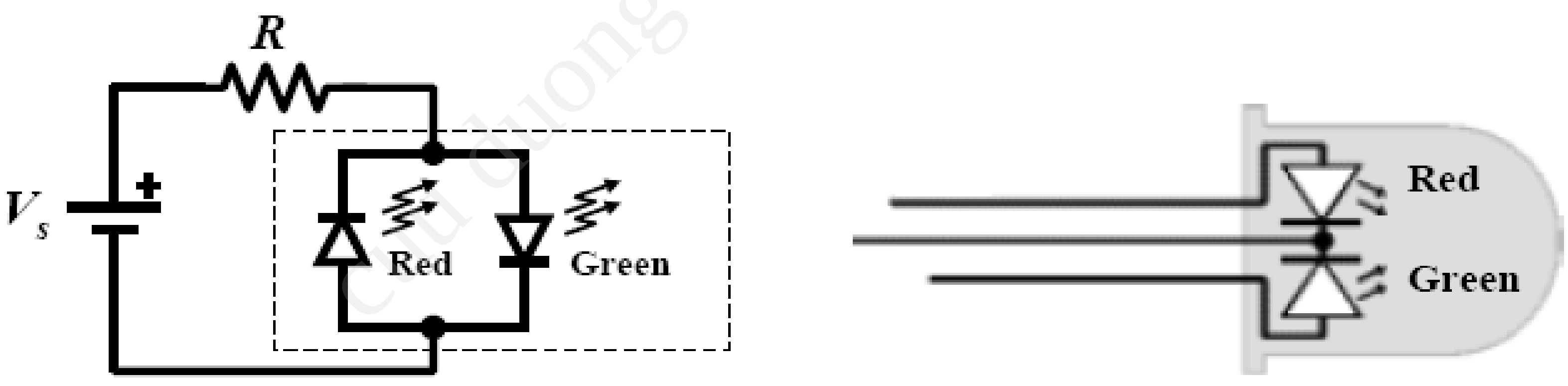
Bicolor LED



Common Cathode



Common Anode



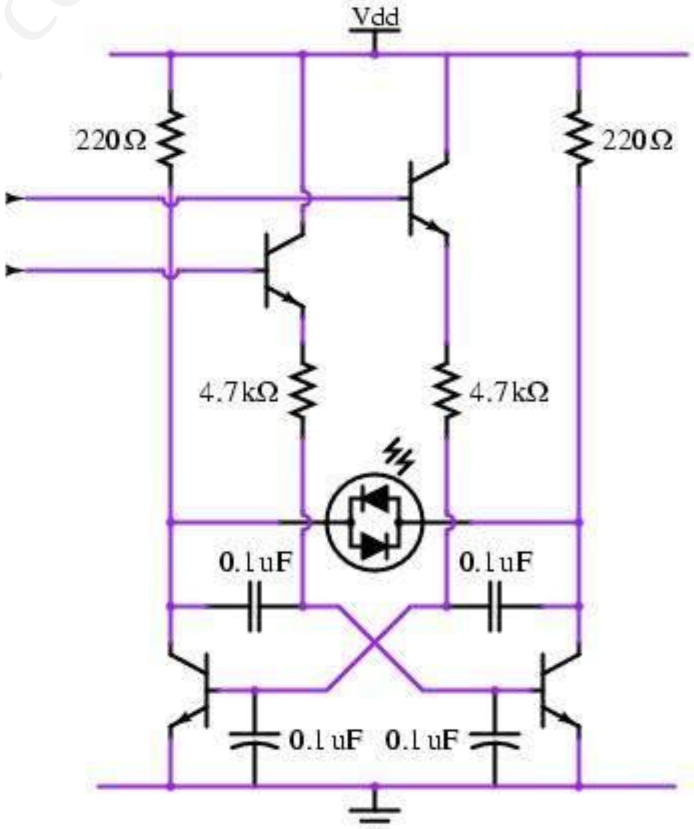
(a) (b)

(a) A current polarity indicator using two LEDs (dashed box represents a part packaged and sold as a “bi-color” LED).
(b) Configuration for bi-color/tri-state LED.

Ex: A Bicolor LED Driver

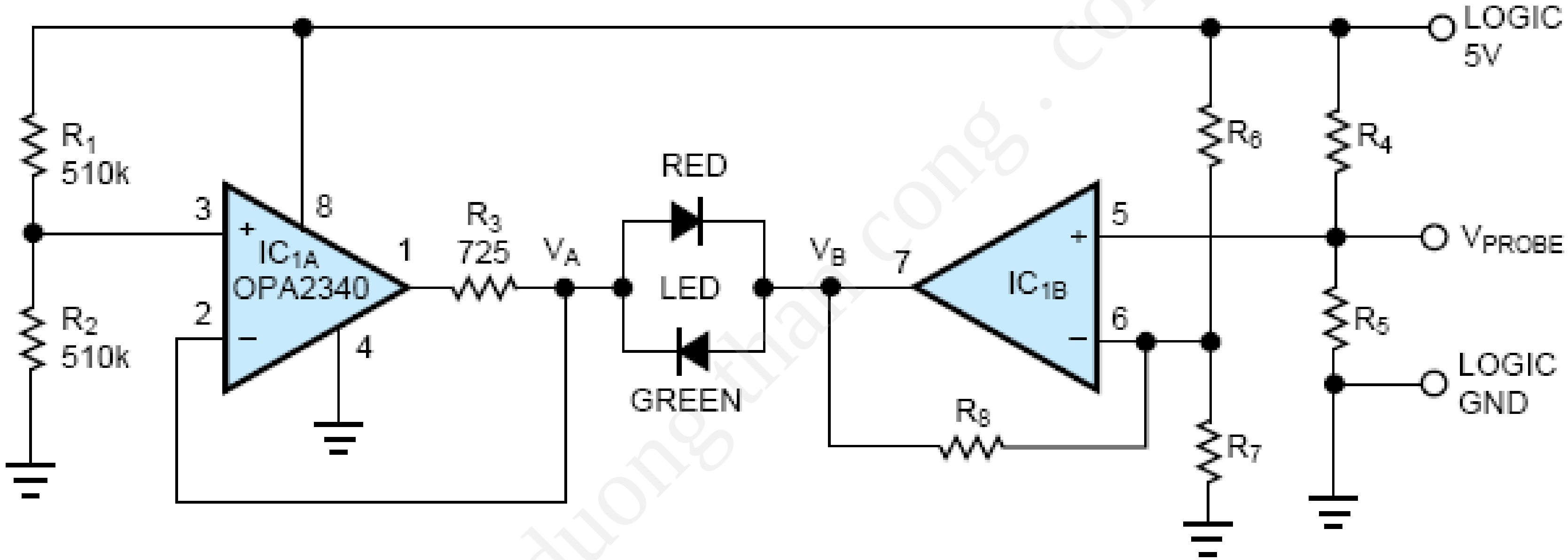
The two control transistors supply controllable bias to the transistor bases of an astable multivibrator, and the LED is directly driven from the oscillation transistors. When both control transistors are off, neither transistor conducts, so the LED stays off. When one or the other, but not both, control transistors is on, one of the oscillation transistors will turn on, but since the other is in cutoff, the feedback path is broken and the LED will be illuminated in a solid color. When both control transistors are on, the feedback loop is closed and the multivibrator begins to oscillate, lighting the LED up in an amber color.

The circuit works quite well in practice. The transistors can be essentially any general purpose type, as this does not stress them particularly (for ex: BC548B, any transistor with a beta of 100 or more).



Simple logic probe uses bicolor LED

FIGURE 1



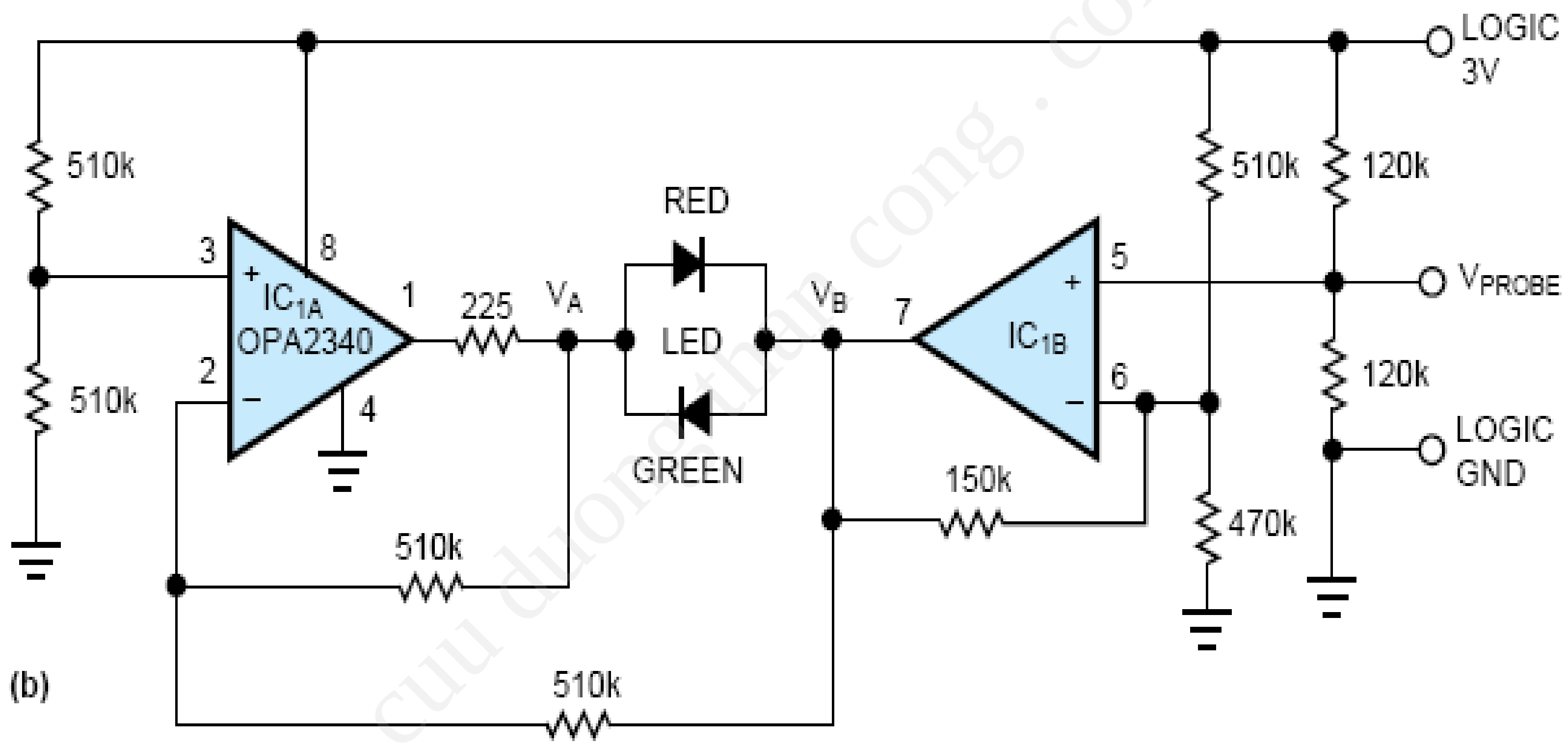
NOTE:
LED=RADIO SHACK 276-012.

(a)

RESISTOR	5V CMOS	TTL
R_4	160k	250k
R_5	120k	100k
R_6	510k	820k
R_7	270k	220k
R_8	180k	470k

A simple handheld logic probe uses a rail-to-rail op amp and a bicolor LED

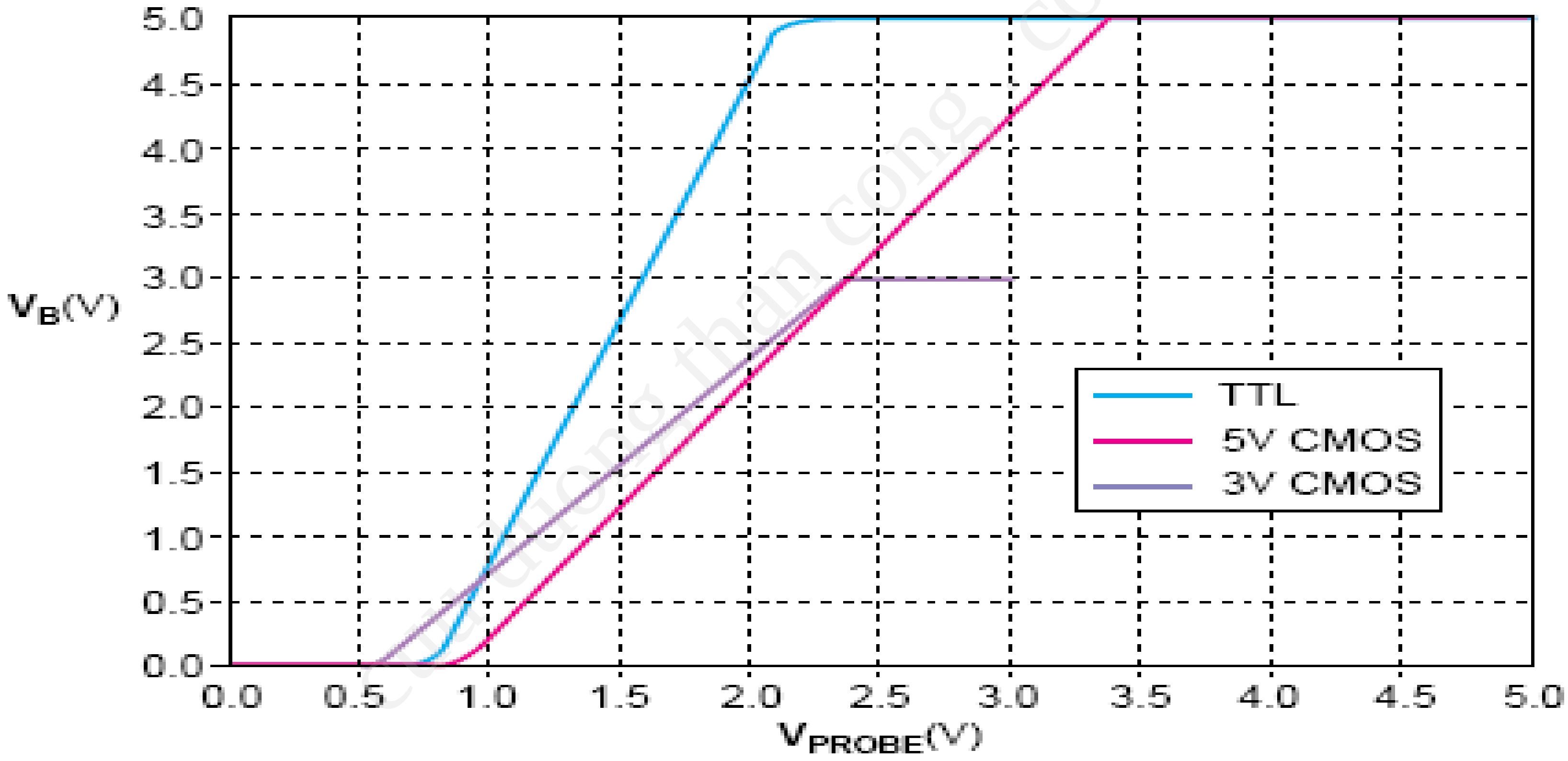
Simple logic probe uses bicolor LED (2/3)



A modified probe circuit works with 3V CMOS logic

Simple logic probe uses bicolor LED (3/3)

FIGURE 2



The output of IC1B, VB, limits at either the positive or negative supply rail depending on the probe voltage.

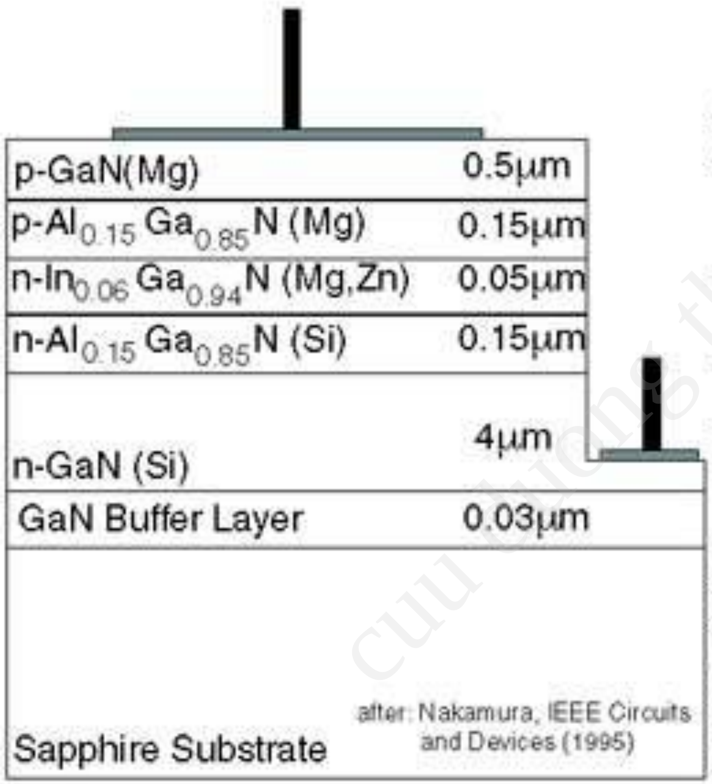
Blue and white LED

BLUE LED

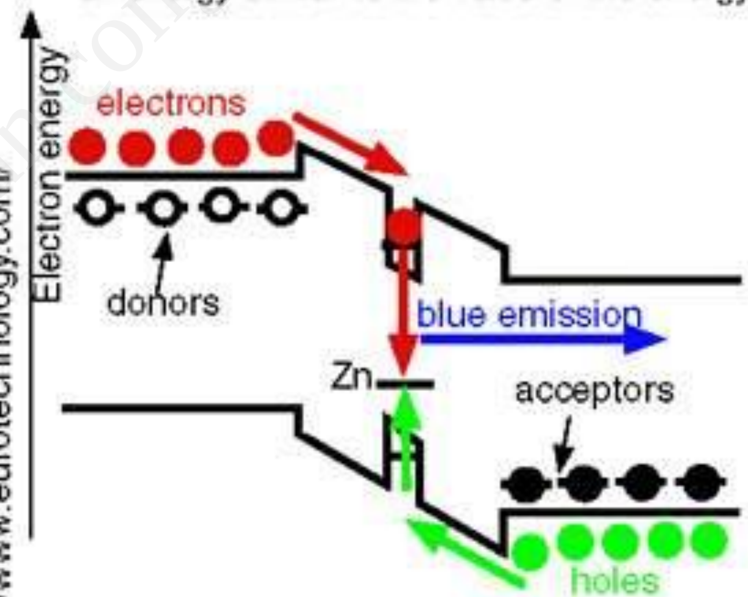

NASDAQ
NASDAQ
NASDAQ
NASDAQ
NASDAQ
Condé Nast

WHAT IS A BLUE LIGHT EMITTING DIODE (LED)

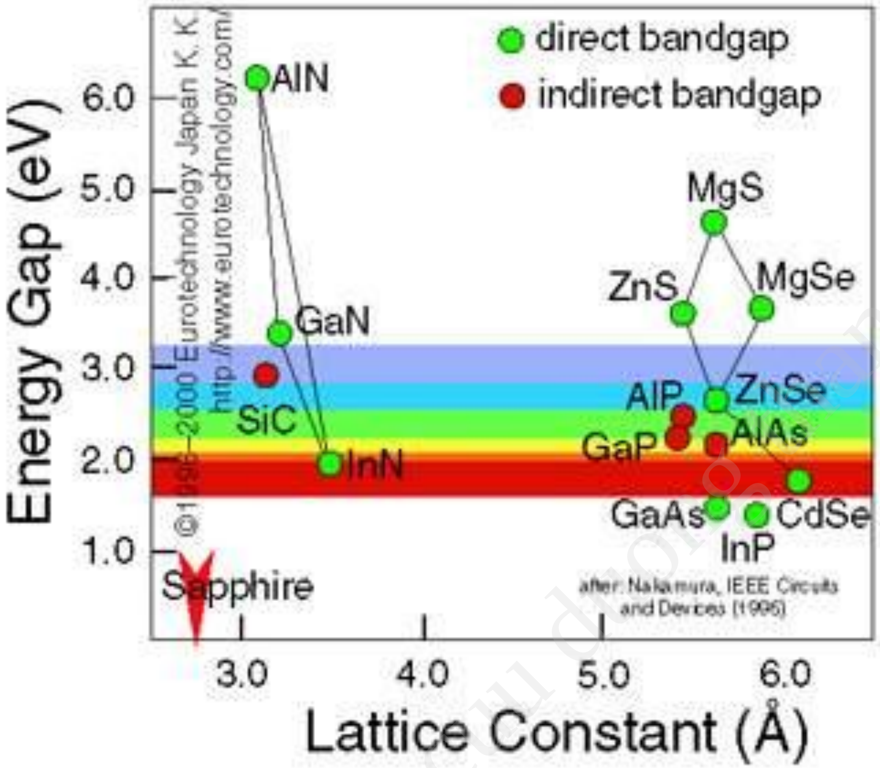
(a) A light-emitting semiconductor diode (LED) or a laser diode (LD) both consist of a stack of extremely thin and precisely grown semiconductor layers of different materials



(b) A light emitting diode (LED) consists of a stack of n-type (left hand side) and a stack of p-type (right hand side) material, forming a "p-n junction". Electrons (red) and holes (green) follow the potential gradient of an applied voltage and recombine in the region of the p-n junction. The photons of the emitted light have an energy similar to the value of the energy gap.



WHY GALLIUM NITRIDE (ALGAN/INGAN)?



- AlN, GaN, InN materials all have a direct band gap, i.e. the optical transitions across the bandgap are "allowed" and therefore much stronger than in the case of indirect bandgaps (which have "forbidden" transitions), as in the case of Silicon Carbide (SiC).
- Before Nichia brought GaN blue LEDs on the market, commercial blue LEDs used SiC, which are much less efficient due to the indirect bandgap
- Before Shuji Nakamura commercialized GaN blue LEDs it was generally thought that II-VI compounds were the path to blue LEDs and Lasers however defects in these materials could not be controlled sufficiently and the life-time of the devices was too short

Applications of Blue LEDs

- Blue LEDs are important for the development of high-information-density storage on optical disks, as well as a host of other applications such as high-resolution television and computer displays, image scanners and color printers, biomedical diagnostic instruments, and remote sensing.

Ways to obtain Blue Light

- doubling the frequency of red or infrared laser diodes (Used by Matsushita and Hitachi)
- The material used for the diode was gallium nitride GaN. Nichia has also produced an InGaN laser diode which lases in the blue-violet region of the spectrum. (Japan in 1994)

Shuji Nakamura

Innovative MOCVD Technique

- Nakamura's road to that invention began with his development of a new technique for Metal-Organic Chemical Vapor Deposition (MOCVD).
- With the conventional MOCVD technique, semiconductors are made by flowing reactant gases over a substrate. Nakamura pioneered a method whereby the gases flow in two directions instead of one, thereby improving the material quality.
- That novel MOCVD technique enabled Nakamura to make a blue LED. And the blue LED lead to the white LED and the blue laser.

What Nakamura exactly did?

- What Nakamura did was to figure out how to grow the crystal so that it would have the n and p semiconductor structure that would create "quantum wells" for the electrons at the junction. One key thing he did to create the wells was to add indium to the gallium nitride crystal. Without the indium, the gallium nitride crystal produces a higher frequency ultraviolet light, which is not visible.

- The addition of indium results in lowering the frequency of the emitted photons to visible blue, but the indium also creates the quantum well effect, so that electrons falling into the passing holes first fall into the well and therefore collect en mass before being injected into the holes. That massing in the well creates a more vigorous injection.

Three Key steps to GaN devices

THREE KEY DIFFICULTIES HAD TO BE SOLVED:

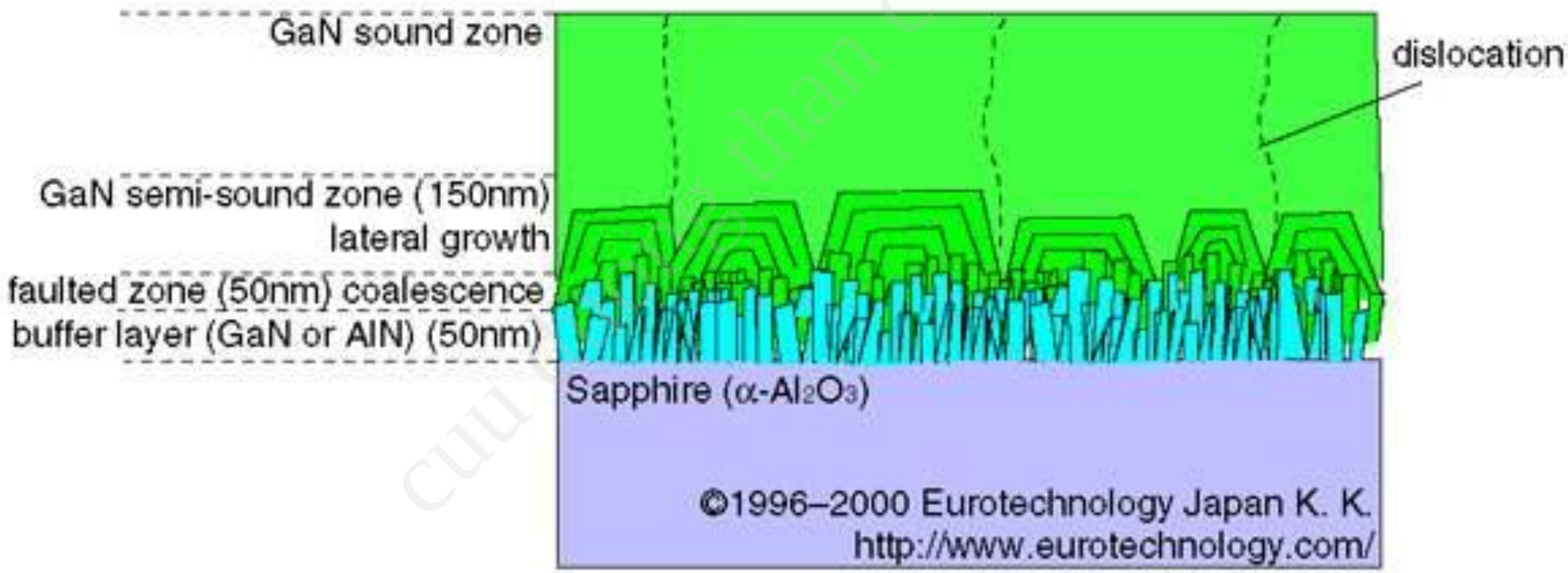
1. Lattice mismatch
   - GaN is grown on Sapphire, which has a 15% smaller lattice constant than GaN, and different thermal expansion, leading to a very high defect density and cracking of the layers when the structures are cooled down after growth
   - Akasaki solved this problem by developing AlN buffer layers
   - Nakamura grew GaAlN buffer layers
2. High growth temperature
   - thermal convection inhibits growth
   - **Nakamura solved this problem with his two-flow growth reactor** (this invention by Shuji Nakamura is at the core of the US$ 600 million law suits before the Courts of Japan between Shuji Nakamura and Nichia Chemical Industries)
3. p-doping was impossible
   - A semiconductor laser, semiconductor light emitting diode, transistor structures and other device structures require pn-junctions, I.e. junctions between p-type and n-type materials. Previous to Akasaki's work p-type doping of GaN was impossibly
   - Akasaki demonstrated p-type material which was e-beam annealed
   - Nakamura found that annealing in Ammonia gas passivated the acceptors and solved this problem

1. Lattice Mismatch (A)

- Choice of substrate
  - Silicon Carbide (SiC): good lattice matching, very expensive, patent issues
  - Sapphire: used at present for most devices
  - Ideally: GaN. However, GaN substrate wafers have not been available. Once they become available, it is expected that GaN devices grown on GaN will have much better properties than devices grown on Sapphire with high lattice mismatch
- Sapphire as substrate
  - 15% difference in lattice constants between Sapphire and GaN and very large difference in thermal expansion initially made growth of devices impossible.
  - Akasaki solved this issue by designing and growing a AlN buffer layer (Akasaki US-Patent 4855249, Applied Physics Letters)
  - Nakamura grew GaAlN buffer layers (Nakamura US-Patent 5290393, Japanese Journal of Applied Physics)

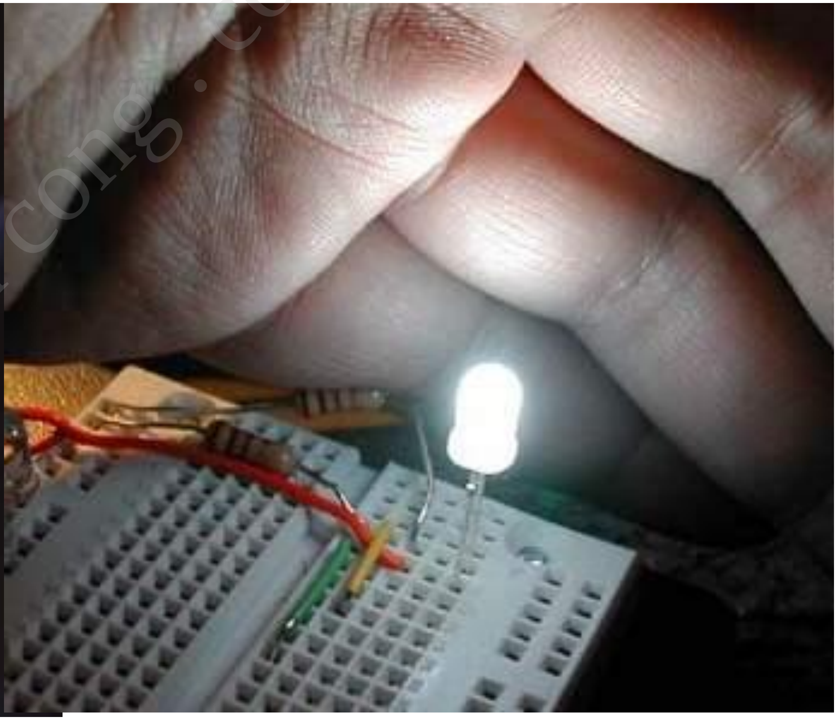
1. Lattice Mismatch (B)

- Problem: large lattice mismatch and large difference in thermal expansion between Sapphire substrate and GaN/AlN
- Solution: AlN Buffer layer (Akasaki, US-Patent 4855249, Applied Physics Letters
- Solution: GaAlN Buffer layer (Nakamura, US-Patent 5290393, Japanese Journal of Applied Physics)
- Ideal solution for the future: GaN substrates (still need to be developed, recent progress looks promising)



after: Akasaki (APL, 1986)

White LED



Ways to make white LED

- Rarely used: Blue LED added to existing red and green LEDs.

- Most "white" LEDs in production today use a 450 nm – 470 nm blue GaN (gallium nitride) LED covered by a yellowish phosphor coating usually made of cerium-doped yttrium aluminum garnet .(“Lunar White” Nichia 1996)

- White LEDs can also be made by coating near ultraviolet (NUV) emitting LEDs with a mixture of high efficiency europium based red and blue emitting phosphors plus green emitting copper and aluminum doped zinc sulfide (ZnS:Cu,Al) similar to fluorescent lamps.

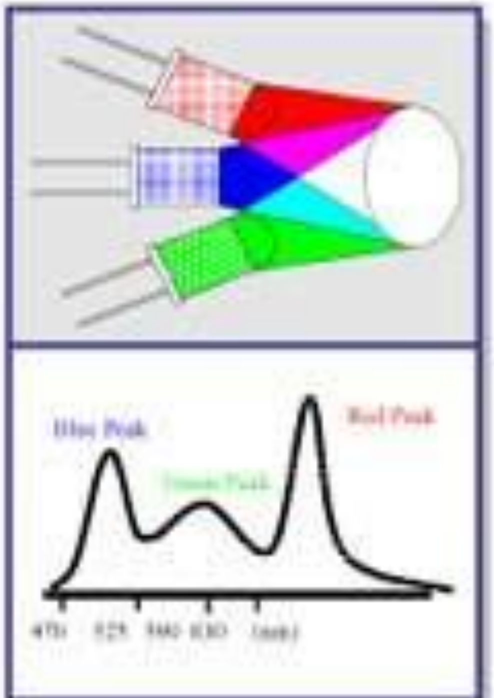
Continued…

- The newest method used to produce white light LEDs uses no phosphors at all and is based on homoepitaxially grown zinc selenide (ZnSe) on a ZnSe substrate which simultaneously emits blue light from its active region and yellow light from the substrate.

- A new technique just developed by Michael Bowers, a graduate student at Vanderbilt University in Nashville, involves coating a blue LED with quantum dots that glow white in response to the blue light from the LED. This technique produces a warm, yellowish-white light similar to that produced by incandescent bulbs

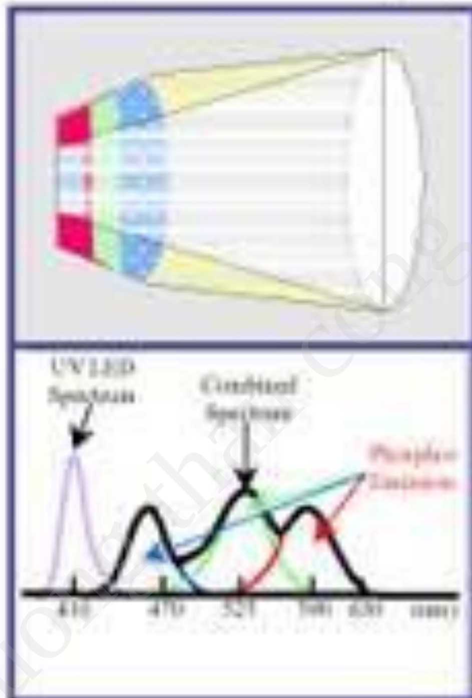
Generating White Light with LEDs

Red + Green + Blue LEDs



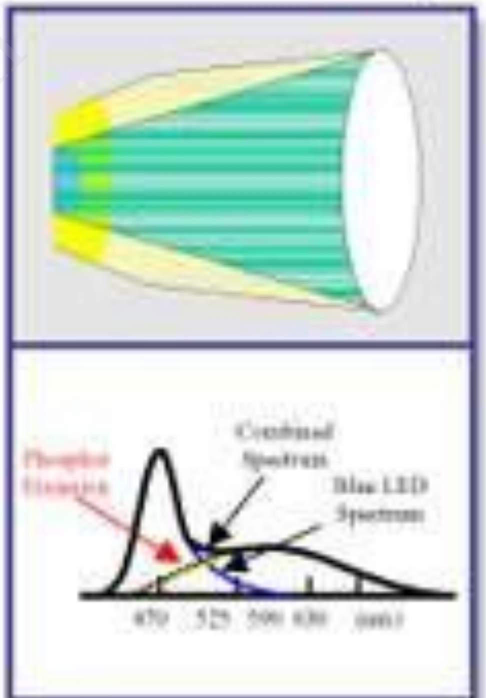
- Dynamic color tuning
- Excellent color rendering
- Large color gamut

UV LED + RGB Phosphor



- White point tunable by phosphors
- Excellent color rendering
- Simple to create white

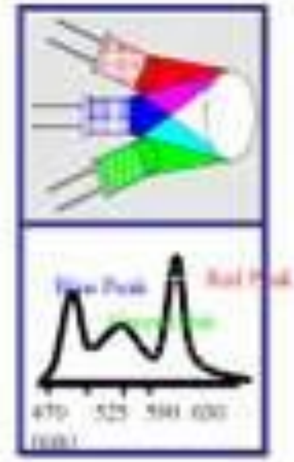
Blue LED + Yellow Phosphor



- Simple to create white
- Good color rendering

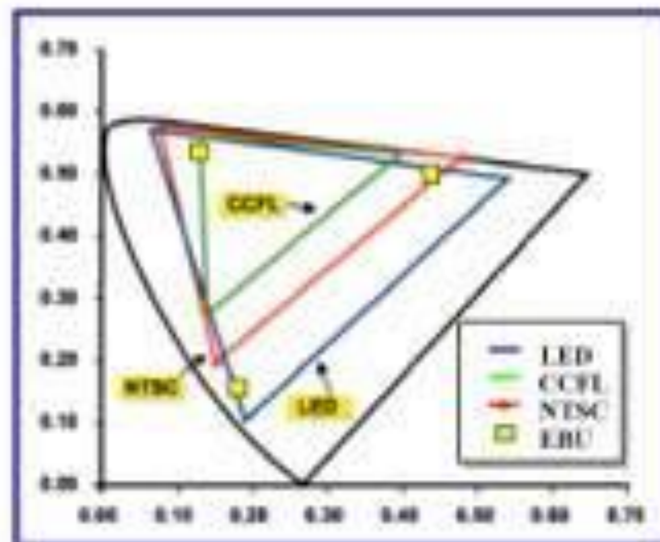
There are various ways to create white light from LEDs, each with specific advantages.

Creating white light- the RGB Solution



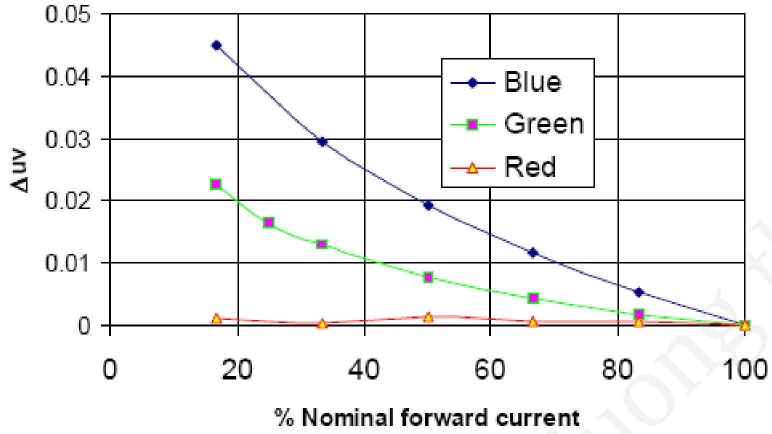
Combining Red, Green and Blue LEDs

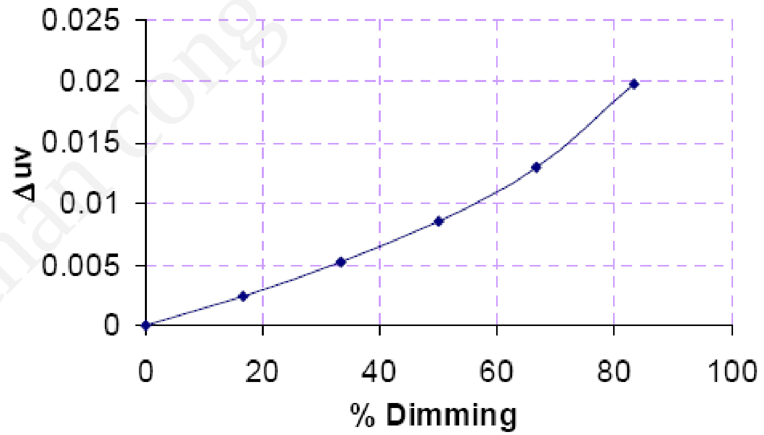
- Advantages
  - Long term likely the most efficient!
  - Dynamic tuning of color temperature possible!
  - Excellent color rendering!
  - Very large color Gamut available!
- Challenges
  - Color mixing can be tricky!
  - Yellow-Green Gap!

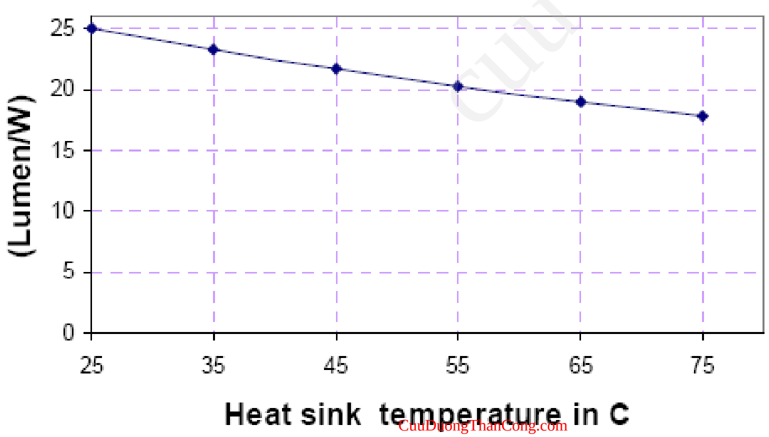


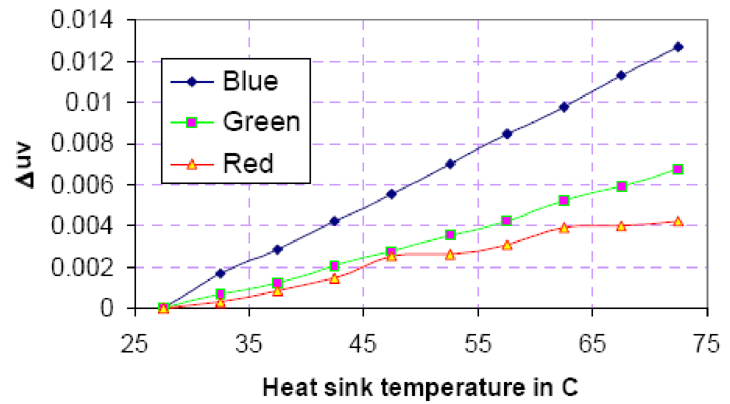
RGB problems

- wavelength and lumen output change by:
  - » Temperature
  - » Time
  - » Forward Current

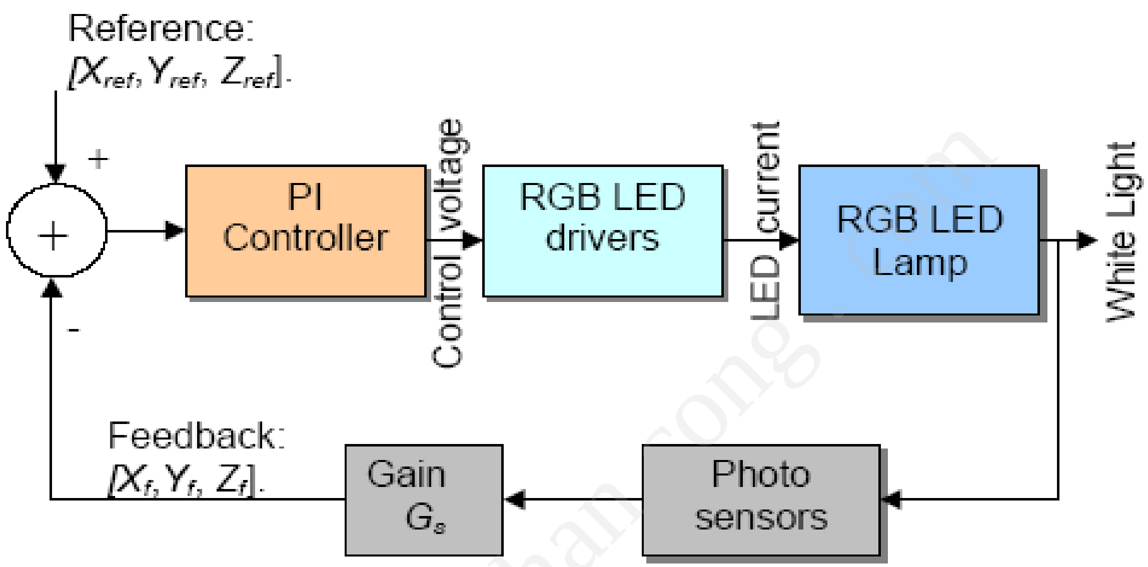


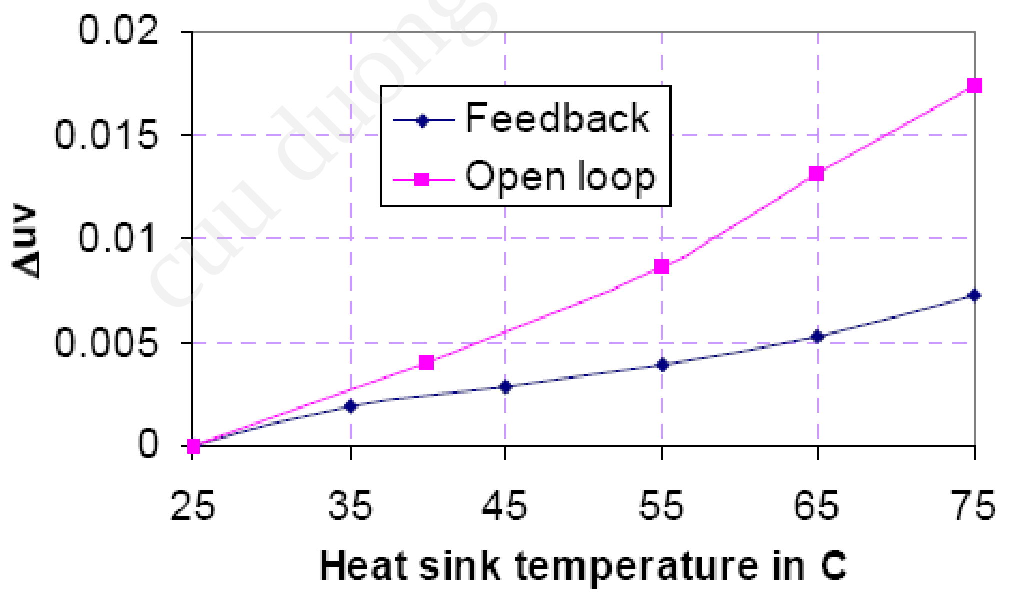




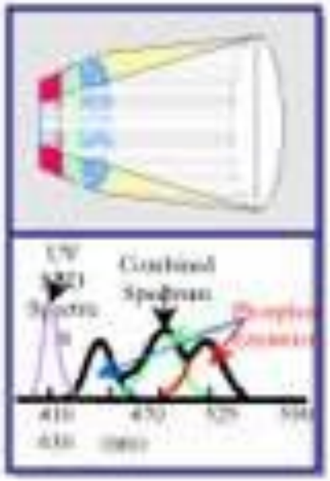


Solution


Reference:
[X_{ref}, Y_{ref}, Z_{ref}].
+
PI Controller
Control voltage
RGB LED drivers
LED current
RGB LED Lamp
White Light
Feedback:
[X_f, Y_f, Z_f].
-
Gain G_s
Photo sensors


0.02
0.015
0.01
0.005
0
Δuv
Feedback
Open loop
25
35
45
55
65
75
Heat sink temperature in C

Creating white light- UV LED pumped with RGB Phospohors



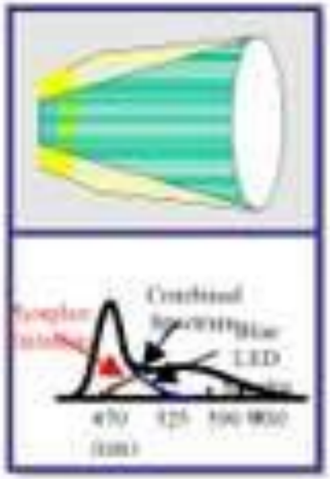
UV LED pumped RGB Phosphors

- Advantages
  - White point determined by phosphors at given temperature and angle! (i.e. tolerant to LED variation)
  - Excellent color rendering possible!
  - Theoretically "Simple to manufacture!" (Looks like TV or Fluorescent lamp except for pump is now UV LED rather than electrons.)
  - Temperature stability of phosphors. (Can be great!)
- Disadvantages
  - Potential for damaging UV light leakage.
  - Fundamental limits on efficiency due to phosphor conversion efficiency, Stokes shift, self absorption,...
  - Variation of white color point with angle can be big!
  - Phosphors are temperature dependent too!!

Creating White Light- Blue LED with Phosphor(s)

White Light from Blue LED + Phosphor(s)

- Advantages:
  - Simple and single Yellow phosphor versions available today!
  - Decent color rendering (Ra = 75 for Blue LED + Yellow Phosphor)
  - Temperature stability of phosphors. (Can be great!)
  - Only Lumileds offers products with uniform white color vs. angle!
- Disadvantages
  - Limits on efficiency due to phosphor conversion efficiency, Stokes shift, self absorption,...
  - Better color rendering (i.e. multi phosphor comes at cost of efficiency)
  - Temperature stability of phosphors not all the same!



Application In Communication

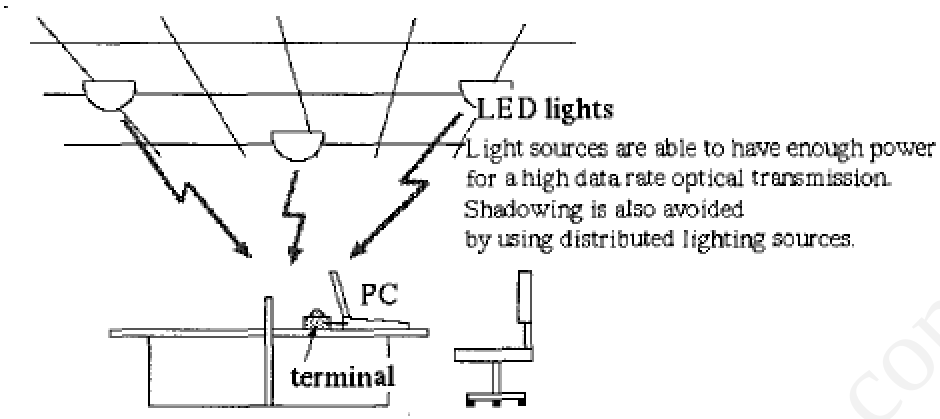
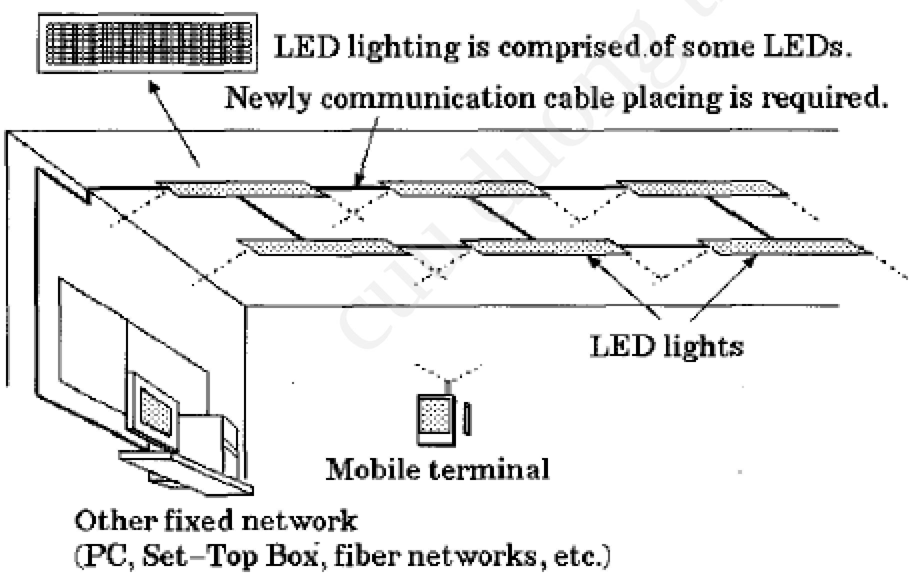


Fig. 1. White LED visible-light communication system.



Ministry of International Trade and Industry of Japan estimates, if LED replaces half of all incandescent and fluorescent lamps currently in use, Japan could save equivalent output of six mid-size power plants, and reduce the production of greenhouse gases