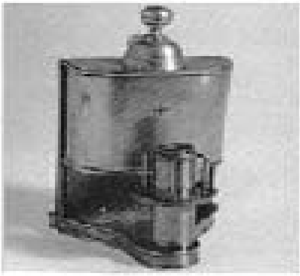
Light Emitting Diode

Contents

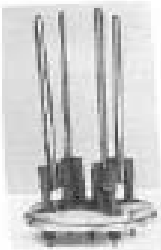
1. History of Lighting

History of lighting

◈ B.C 1000 – the first candle
◈ 1772 - gas lighting
◈ 1784 Agrand the first lamp relied on research (Lavoisier)
◈ 1826 – Limelight – the first solid-state lighting device
(by Thomas Drummond)



Agrand lamp



Yablochkov candle (1876)

Limelight

Edison bulb (1879)

FEBRUARY 9, 1907. ELECTRICAL WORLD.

A Note on Carborundum.

To the Editors of Electrical World:

SIRS:—During an investigation of the unsymmetrical passage of current through a contact of carborundum and other substances a curious phenomenon was noted. On applying a potential of 10 volts between two points on a crystal of carborundum, the crystal gave out a yellowish light. Only one or two specimens could be found which gave a bright glow on such a low voltage, but with 110 volts a large number could be found to glow. In some crystals only edges gave the light and others gave instead of a yellow light green, orange or blue. In all cases tested the glow appears to come from the negative pole, a bright blue-green spark appearing at the positive pole. In a single crystal, if contact is made near the center with the negative pole, and the positive pole is put in contact at any other place, only one section of the crystal will glow and that the same section wherever the positive pole is placed.

There seems to be some connection between the above effect and the e.m.f. produced by a junction of carborundum and another conductor when heated by a direct or alternating current; but the connection may be only secondary as an obvious explanation of the e.m.f. effect is the thermoelectric one. The writer would be glad of references to any published account of an investigation of this or any allied phenomena.

NEW YORK, N. Y. H. J. ROUND.

First paper of LED (1907)

History of LED

1960's –1980's

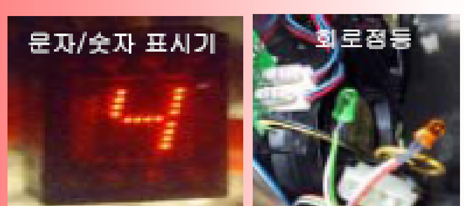
LED is born – comes of age

GaAsP

AlGaAs

세계 최초의 상용 LED (적색) Monsanto(1969)

최초의 고휘도 LED (300 mcd) Fairchild (1980's)



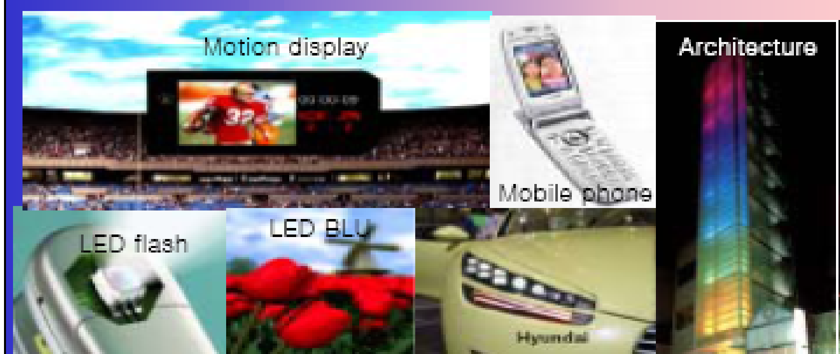
Machinery indicator, Alpha-numeric display

1990's –

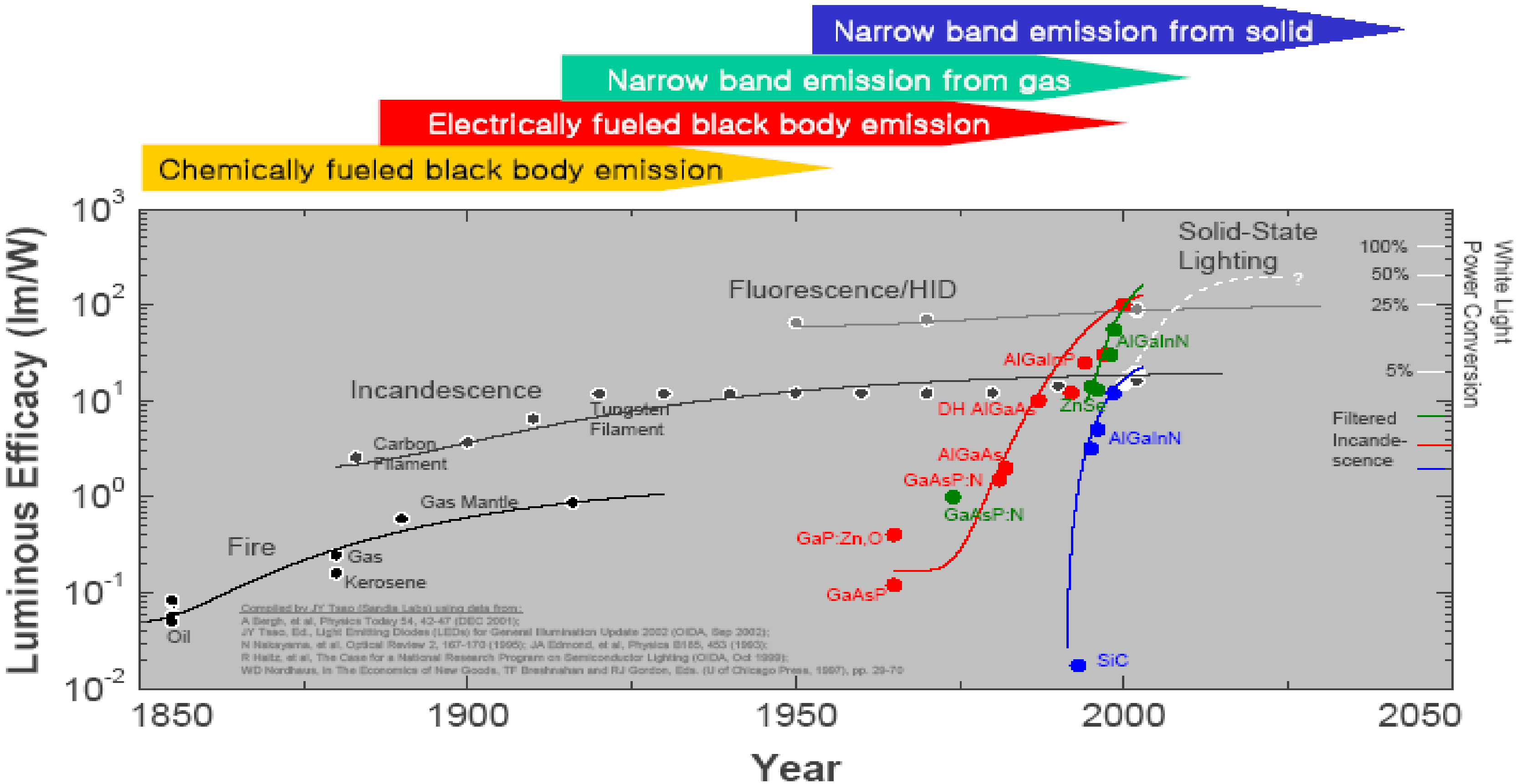
HB LED – new era of LED

AlInGaP

InGaN



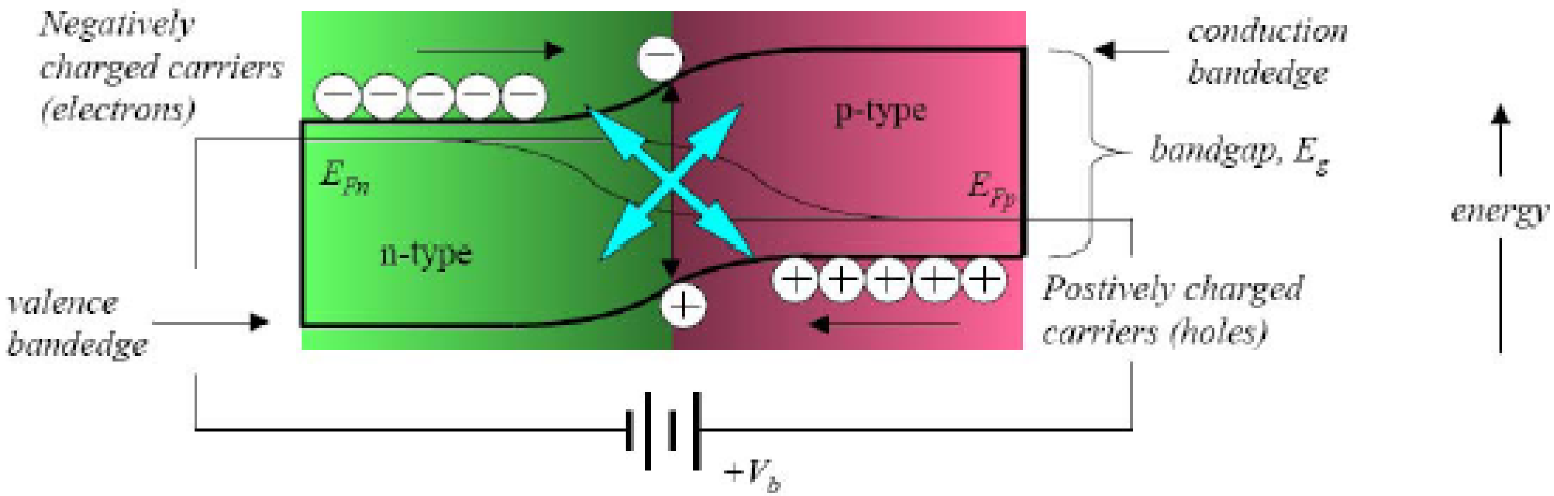
Sign, Signal, Display, Backlight, Task lights



Courtesy of J.Y. Tsao @ Sandia Lab and Prof. Jung Han @ Yale Univ.

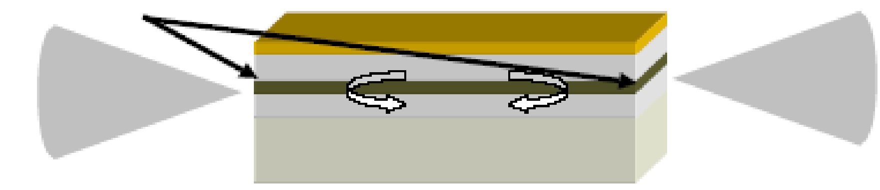
2. What is a light Emitting Diode **(LED)**

LED (Light Emitting Diode)

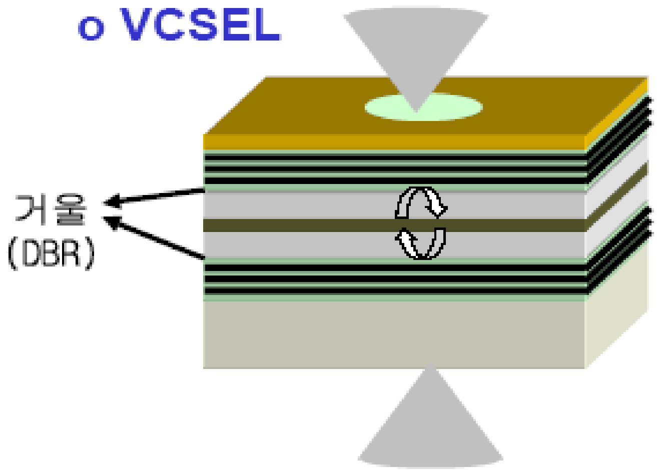


- Impurity doping provides p- and n-type region
- At forward bias, injected electrons and holes recombine
- Energy may be released as radiative (light) or non-radiative (heat)

o Edge-emitting LD

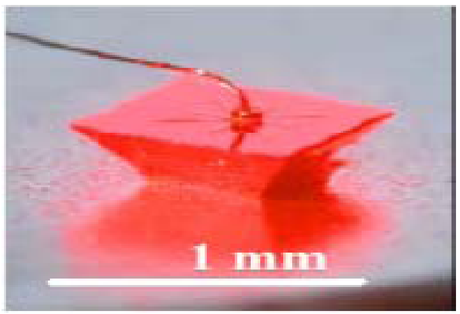


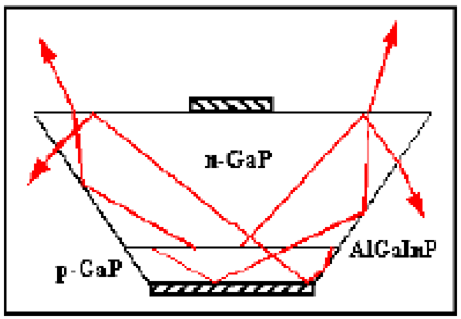
o VCSEL



거울에 의한 반사를 되먹임하여 파장을 선택방출

o LED (Light Emitting Diode)





거울에 의한 반사를 최소화하여 추출효율 극대화

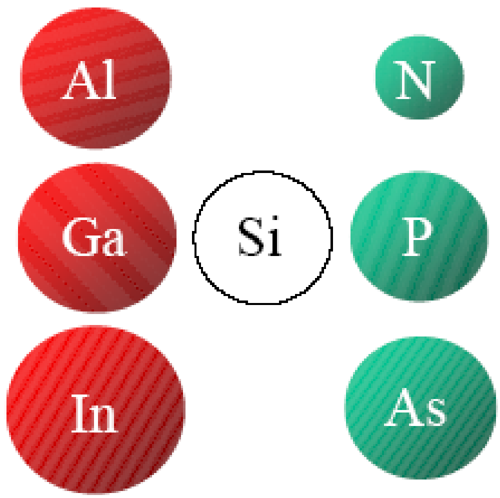
LED fabrication

Bulk Substrate Crystal Growth & Machining → Epitaxial Deposition Of LED → Wafer Fabrication → Die Fabrication → Final Product Assembly

e.g., GaAs, Al_2O_3, SiC

e.g., metal-organic chemical vapor deposition (MOCVD)

LED materials

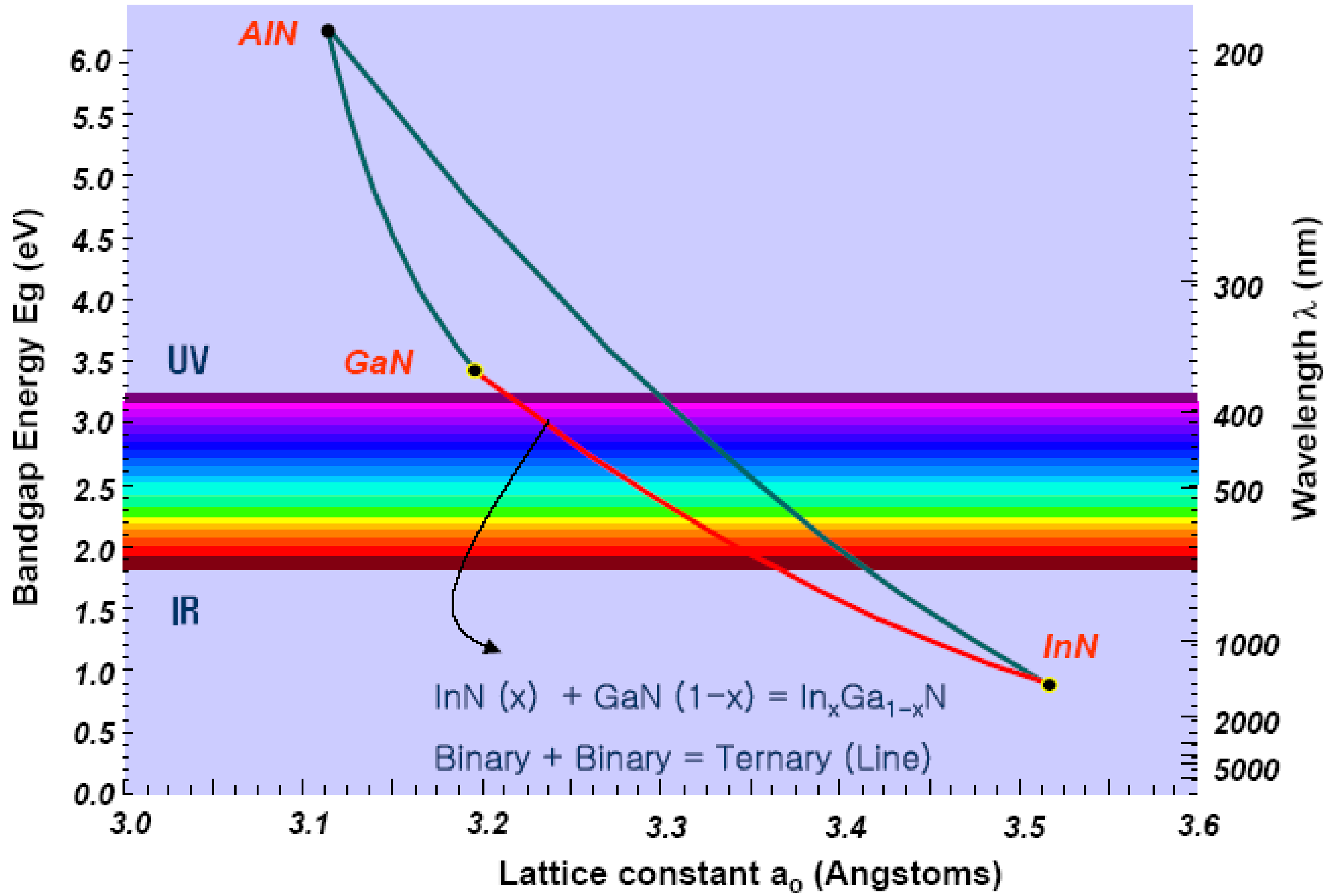


	II	III	IV	V	VI		He
		B	C	N	O	F	Ne
		Al	Si	P	S	Cl	Ar
Cu	Zn	Ga	Ge	As	Se	Br	Kr
Ag	Cd	In	Sn	Sb	Te	I	Xe
Au	Hg	Tl	Pb	Bi	Po	At	Rn

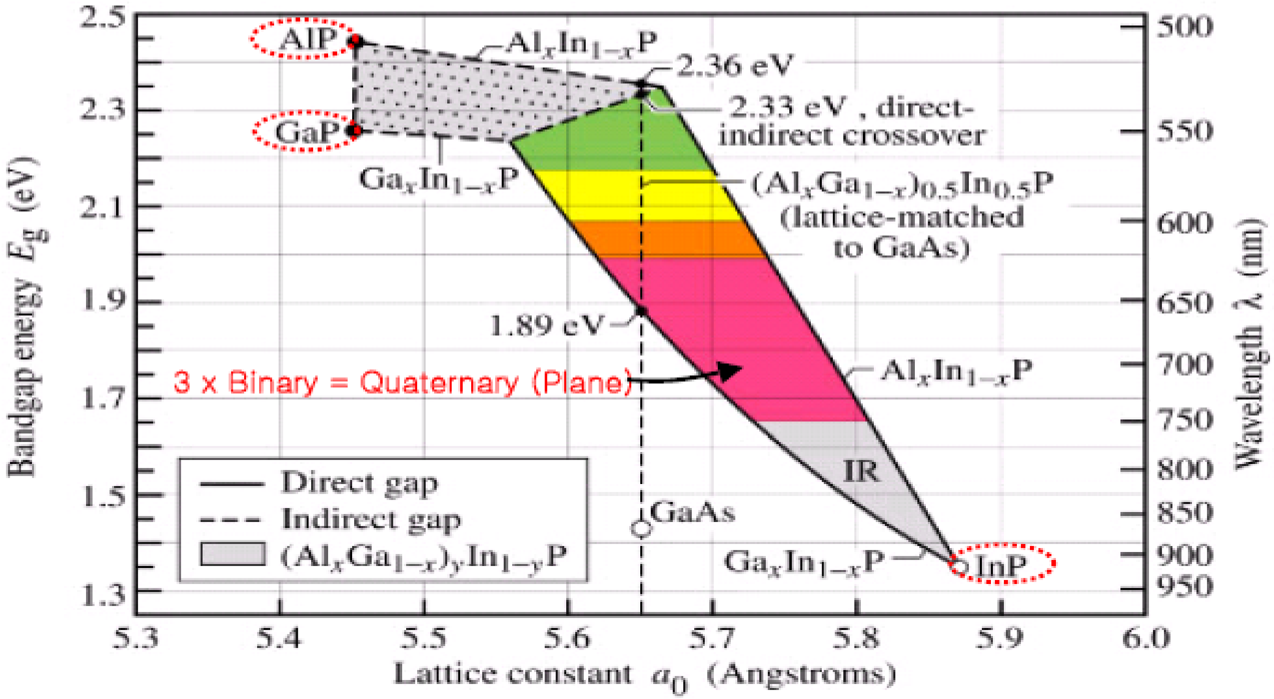
•현재 상용화된 LED는 대부분 화합물 반도체
•대부분 3-5족,3-3-5족, 3-3-3-5족, 3-3-5-5족 결합

•적색 :AlGaAs, InGaAlP
•녹색: InGaN
•청색: InGaN
•UV : GaN, InAlGaN
•IR : GaAs, InGaAs

LED materials(Blue-Green-UV)



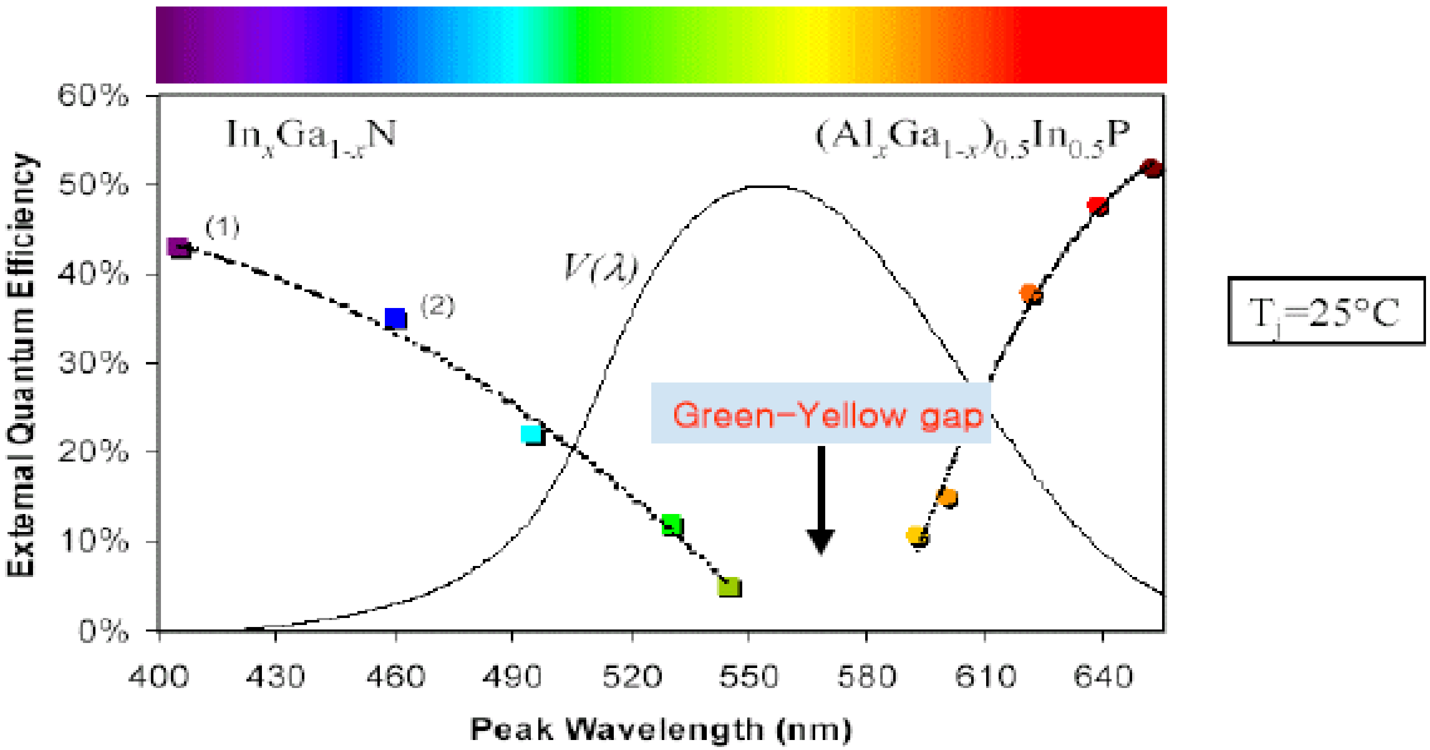
LED materials(Red)



$(Al_xIn_{1-x}P)y + (Ga_xIn_{1-x}P)(1-y) = (Al_yGa_{1-y})_xIn_{1-x}P$

Lattice matching to GaAs @ x=0.5

External Quantum Efficiency



(1) Mitsubishi Cable : III_Vs Review, Vol. 16, No4, p.34(May, 2003)
(2) Nichia Chemical Co. : Yamada et. al., Jpn. J. Appl. Phys. Vol. 41(2002) pp. L 1431-L1433.
Remainder data Lumileds Lighting (InGaN superflux 20mA, AlInGaP Luxeon 1W @ 350mA)

External Quantum efficiency=Internal Quantum efficiency x Extraction Efficiency

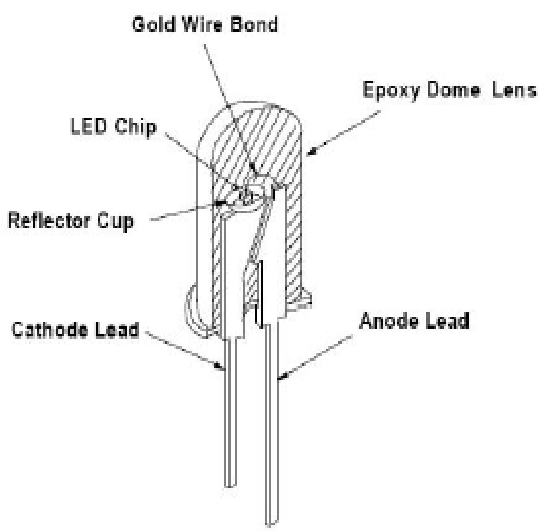
Internal Quantum efficiency : 발광 다이오드(LED)를 통과하는 각각의 전자에 대하여 얼마나 많은 광자가 만들어지는가에 대한 특성 값 LED의 Internal Quantum Efficiency은 반도체 물질의 품질과 활성 영역에 대한 디자인에 의해 결정

Extraction Efficiency : 이렇게 생성된 광자가 반도체 칩 밖으로 빠져 나오는 양에 대한 비율을 의미. 반도체와 주변 물질 사이의 높은 굴절률의 차이로 인해 생성된 많은 광자들은 내부적으로 여러 번 반사를 겪게 되는데, 이 과정을 통해 다시 흡수되기도 함.

External Quantum Efficiency:

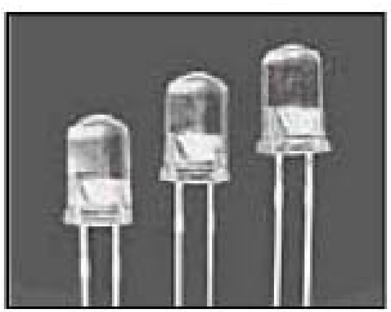
Internal Quantum efficiency * Extraction Efficiency

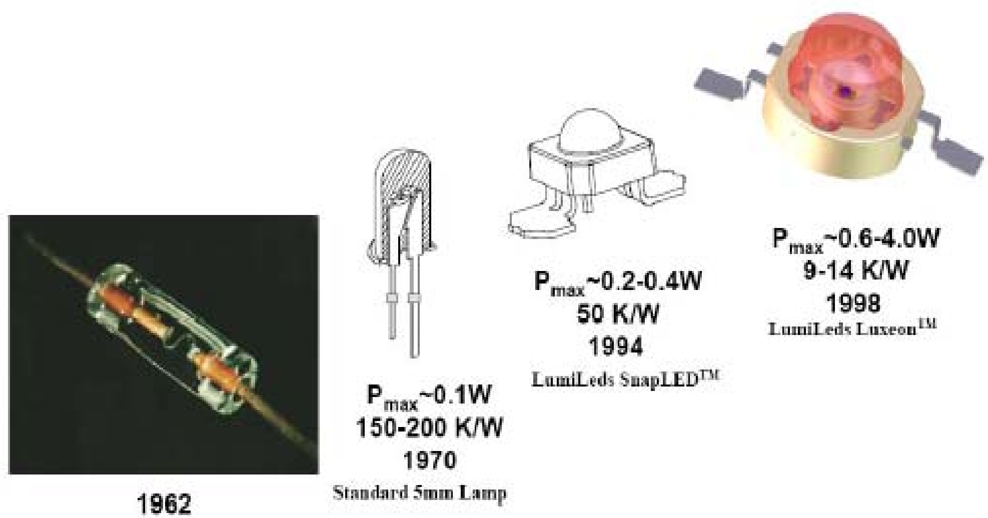
Conventional LED



Limitation :

- Very high thermal resistance (>200K/W)
- Epoxy limited to T~120 ℃
- Input power limited to <0.1W





epoxy

All LED, with exception of communication LEDs, are encapsulated with an opticcally transparent Epoxy

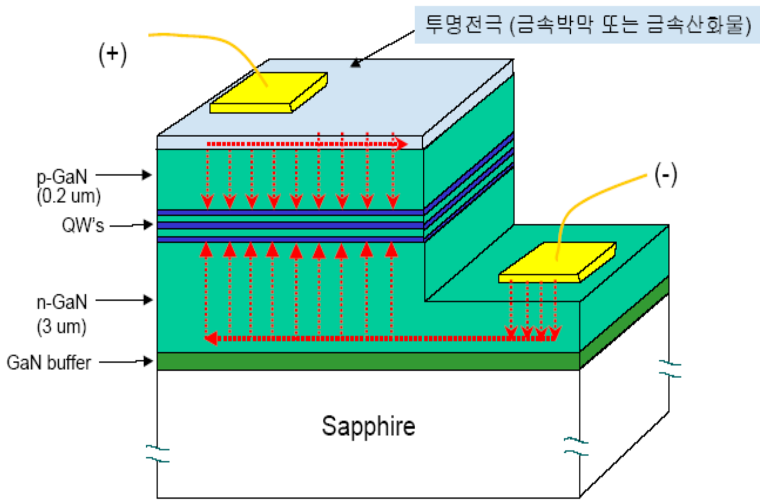
Refractive index : 1.5 ⟶ Refractive index contrast between the semiconductor and air is reduced by epoxy

Shape of epoxy dome : Hemisphere (angle of incident is always normal)
Cylindrical, Rectangular (viewing angle is planar surface normal)

Additional function : protection against mechanical and chemical shock
(LED dies, bonding wire, two metal leads)

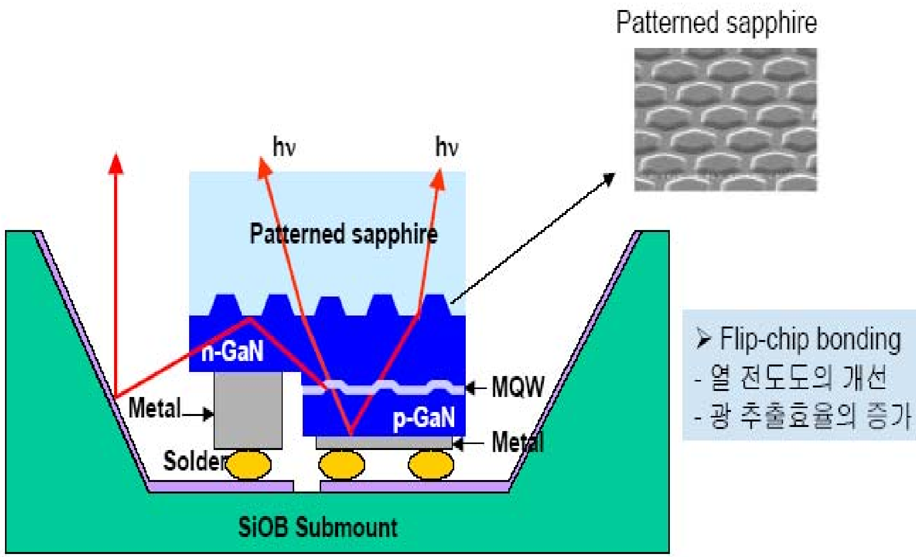
LED Structure & Species

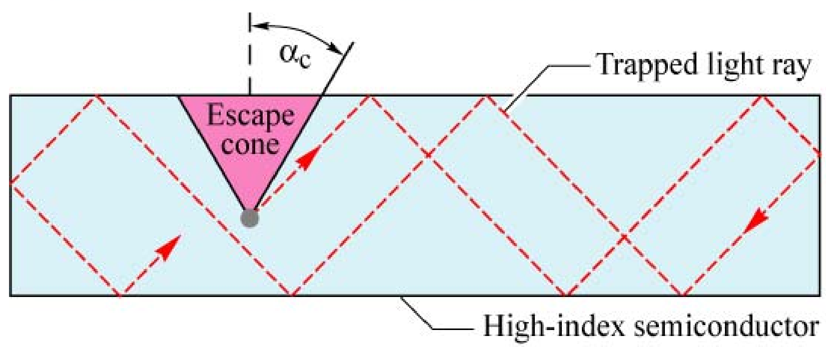
1. LED structure

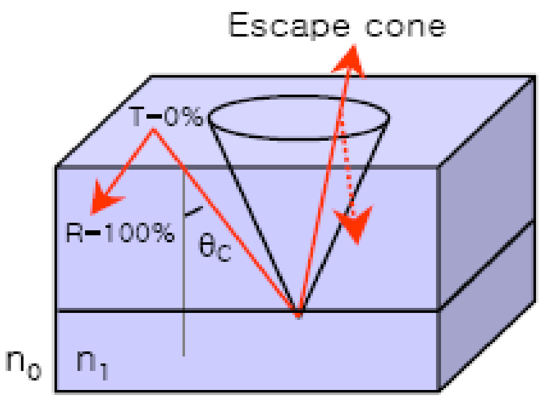


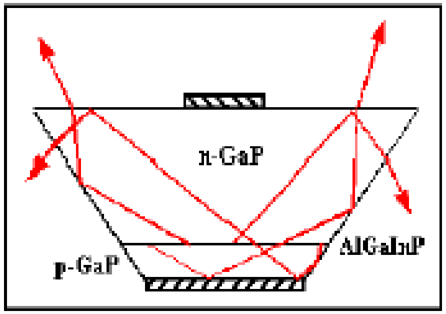
Chip dimension = 0.3 x 0.3 x 0.1 mm^3

2. Flip chip bonding









TS/TIP chip ~ 30배 휘도향상

$\sin \theta_C = n_0/n_1$

When,

$\theta > \theta_C$: Total reflection

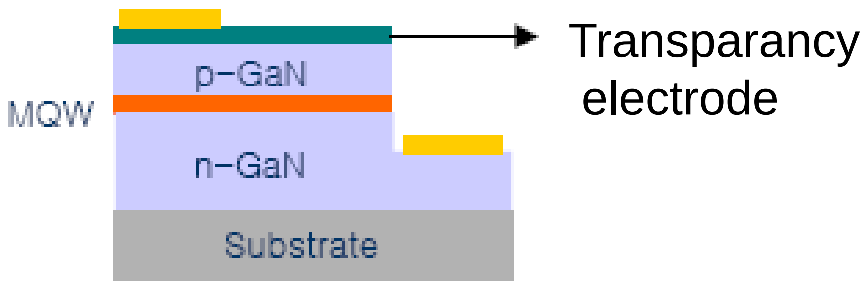
$\theta < \theta_C$: Partial reflection

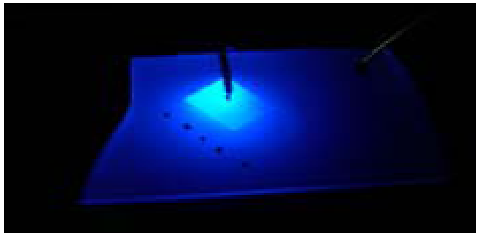
$\theta_C = 24°$ for chip/air

$\theta_C = 37°$ for chip/epoxy (n=1.5)

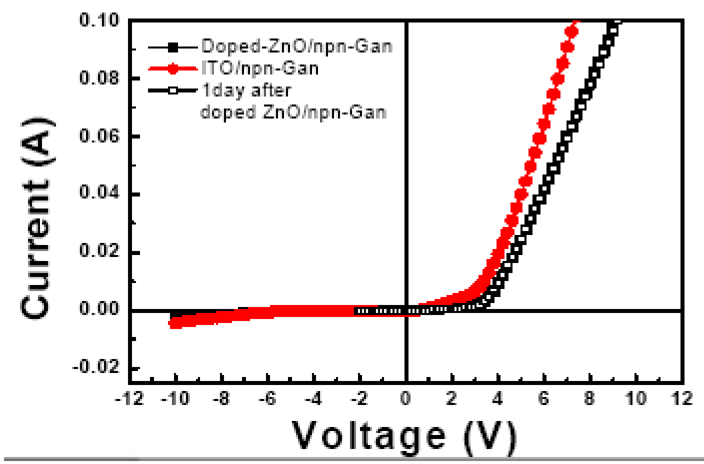
Escape efficiency = 10% for epoxy (n=1.5)

Low resistance & high transparancy electrode





Conventional ITO



ZnO계 사성분 투명전극

Quantum Photonics IC Design Lab.

---- QPID Lab ----

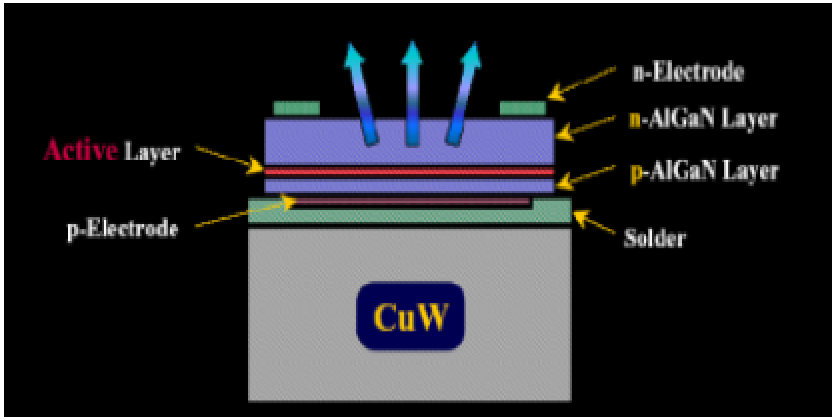
http://www.postech.ac.kr/ee/light

POSTECH

Dept. of Electronic & Electrical Eng.

High Power LED

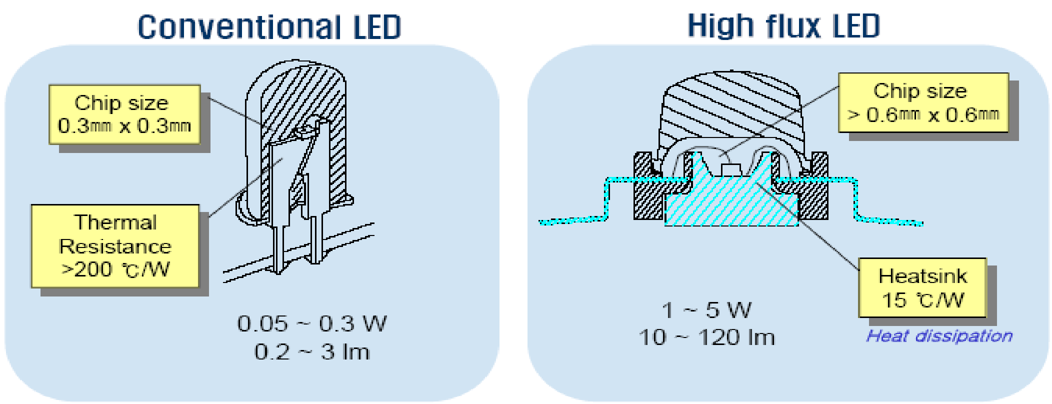
- Nichia's early high-power LED package has been flip-chip bonding type.
- High reflective p-electrode by Ag
- Decrease of absorption of emission light by InGaN layer
- High heat conductivity with CuW
- FWHM λ= 10nm, PO= 400 mW, ηext= 24% VF= 4V



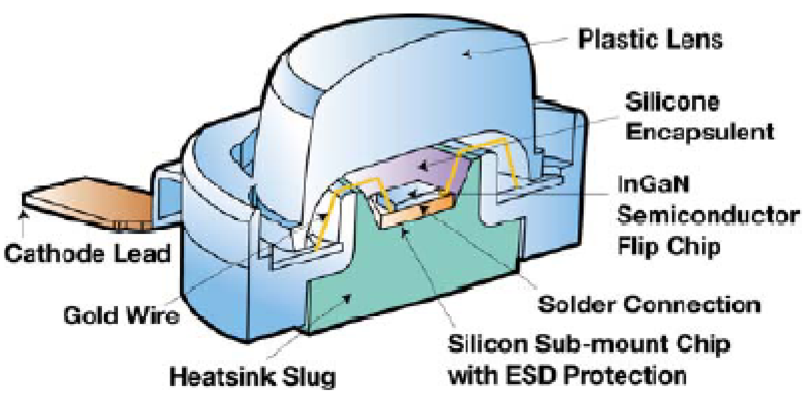
High-power 365nm UV-LED

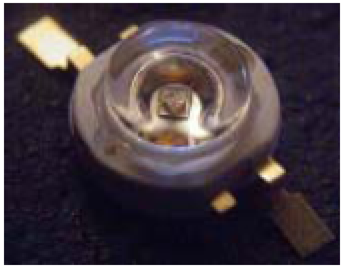
Lumileds

- High flux packaging
  - Temperature increase = red shift , Intensity decrease



- Reduced LED number
- Higher brightness
- Heat problem





Low thermal Resistance
Silicon encapsulent – Good reliability , color uniformity

Development trend

사파이어 기반 LED의 한계

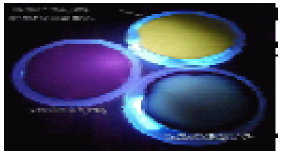
- 근본적인 에피결함에 의한 소자 성능의 한계
- 특허에 의한, 상품화의 원천 봉쇄

상용화 달성

- Sapphire
- SiC
- Si
- GaN, ZnO, Ga2O3..

무결함 LED

저가형 고휘도



UV pumped InGaN on BP/Si

한계의 극복

- 호모기판을 이용한 무결함 LED 의 실현
  → 기판기술이 아직 미완성
- 대체 기판을 이용한 동급 휘도의 LED 구현
  → 기술봉쇄에 대처하는 전략기술 개발

RCLED

RCLED: resonant-cavity light-emitting diode

- a light emitting region inside an optical cavity
- The resonance wavelength of the cavity coincides or in resonance with the emission wavelength of the light-emitting active region of the LED.
- The RCLED is the first practical device making use of spontaneous emission enhancement occurring in microcavities
- The *light intensity* emitted from the RCLED along the axis of the cavity is *higher* compared with conventional LEDs. (enhancement factor: 2 ~ 10)

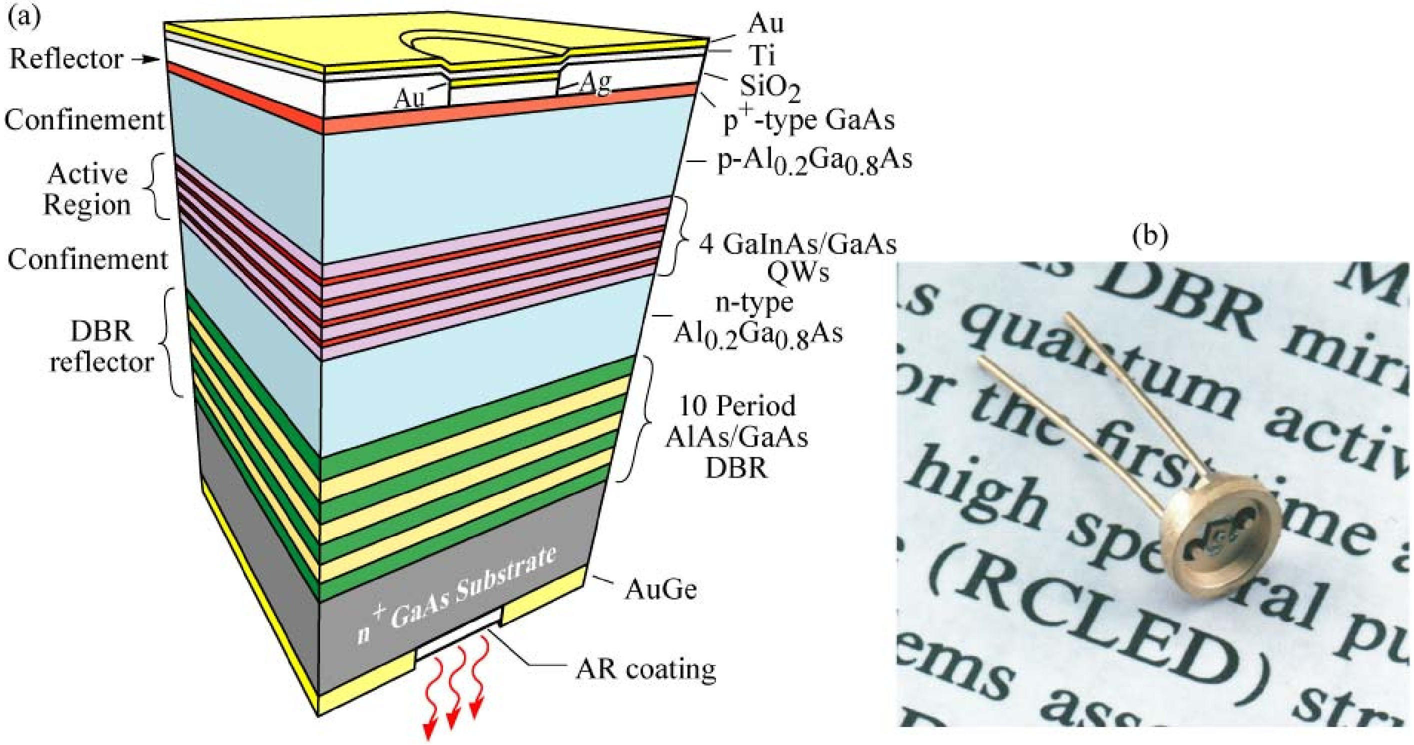
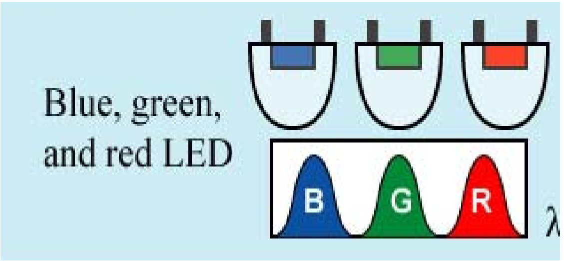


Fig. 15.4. (a) Schematic structure of a substrate-emitting GaInAs/GaAs RCLED consisting of a metal top reflector and a bottom distributed Bragg reflector (DBR). The RCLED emits at 930 nm. The reflectors are an AlAs/GaAs DBR and a Ag top reflector. (b) Picture of the first RCLED (after Schubert *et al.*, 1994).

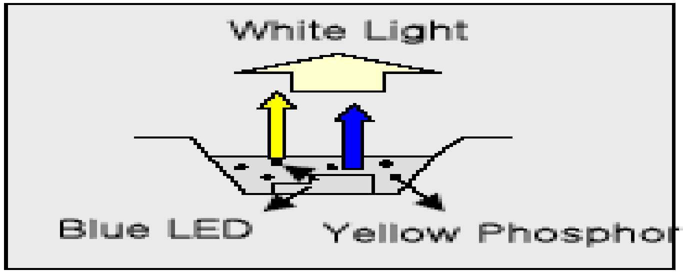
White LED

- Method to make White LED : Lighting, backlight unit, medical light

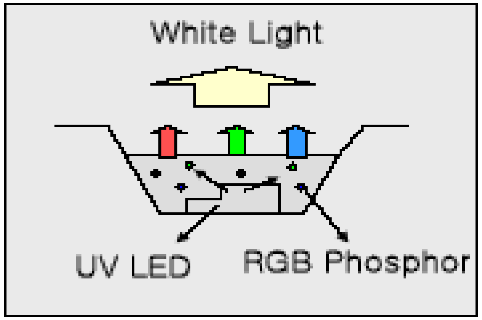
1. R+G+B

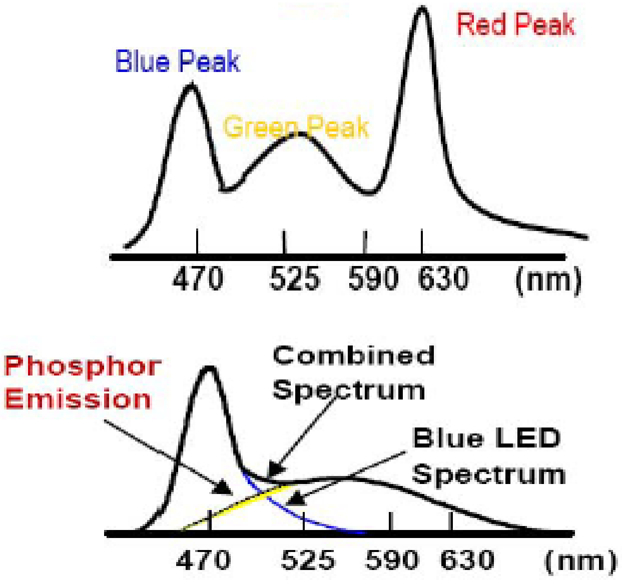


2. Blue LED + Yellow Phosphor



3. UV LED + RGB Phosphor





3. Properties of LED

Photometric

1. Luminous flux: A monochromatic light source emitting an optical power of (1/683) Watt at 555 nm has a luminous intensity of 1 lm

:The photometric quantities are related to the corresponding radiometric quantities by the C.I.E. Standard Luminosity Function

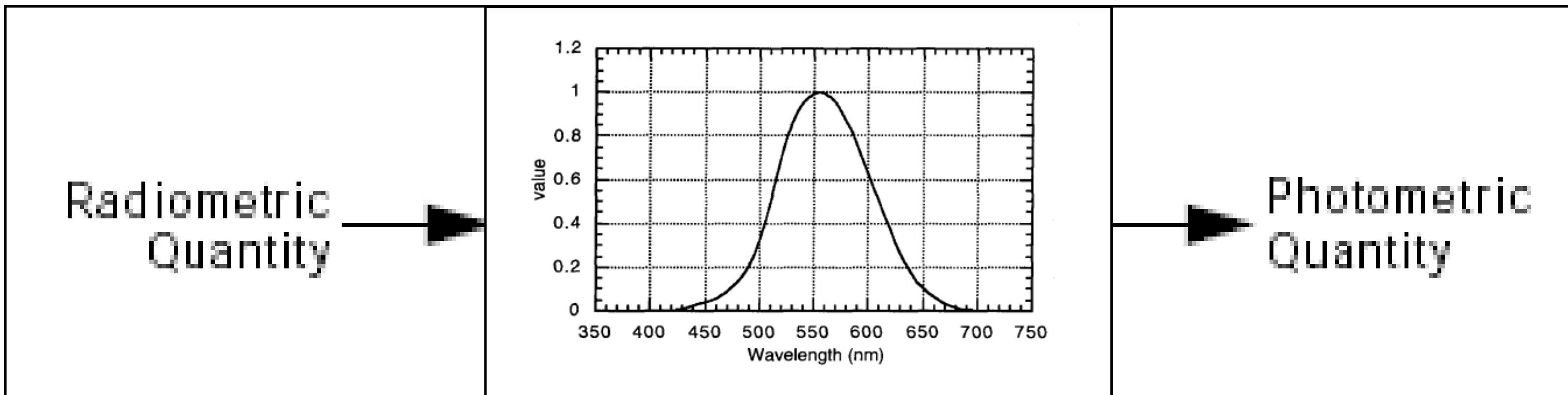


Figure 1 CIE $V(\lambda)$ Function.

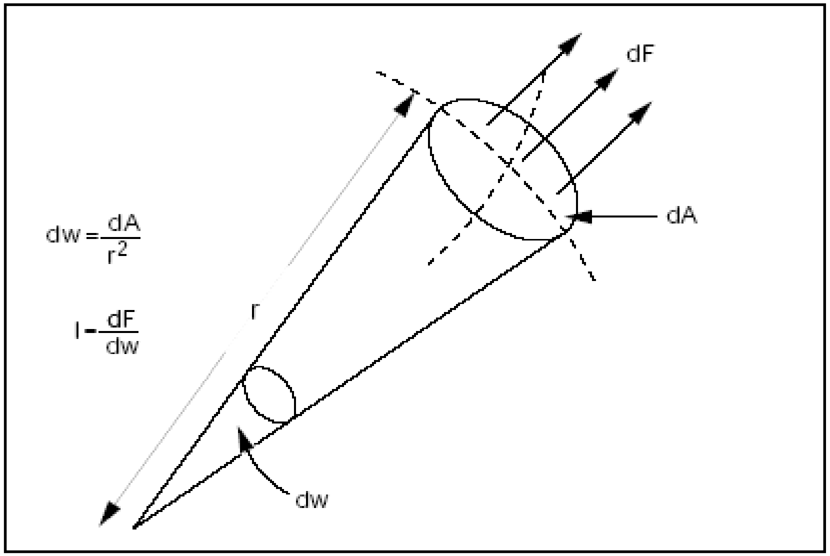
$$X_v = K_m \int_{360\ \mathrm{nm}}^{830\ \mathrm{nm}} X_{e,\lambda} V(\lambda)\, d\lambda$$

Km = 683 lm/W

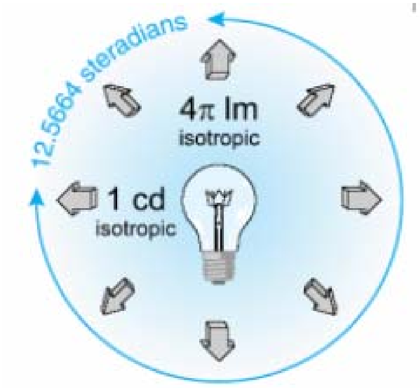
$X_{e,\lambda}$ = radiometric quantity

X_v = photometric quantity

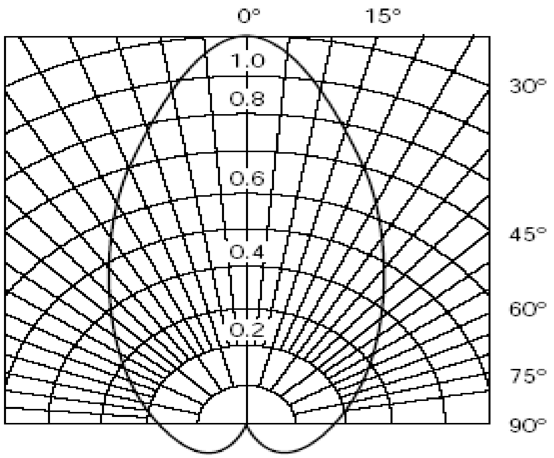
2. Luminous intensity : Cd (lm/sr) :



dw : solid angle
dF: Luminance flux



Isotropic



anisotropic

Luminous efficiency= lm/W(IV) , Luminous efficacy= lm/W(radiometric power)

3.View angle

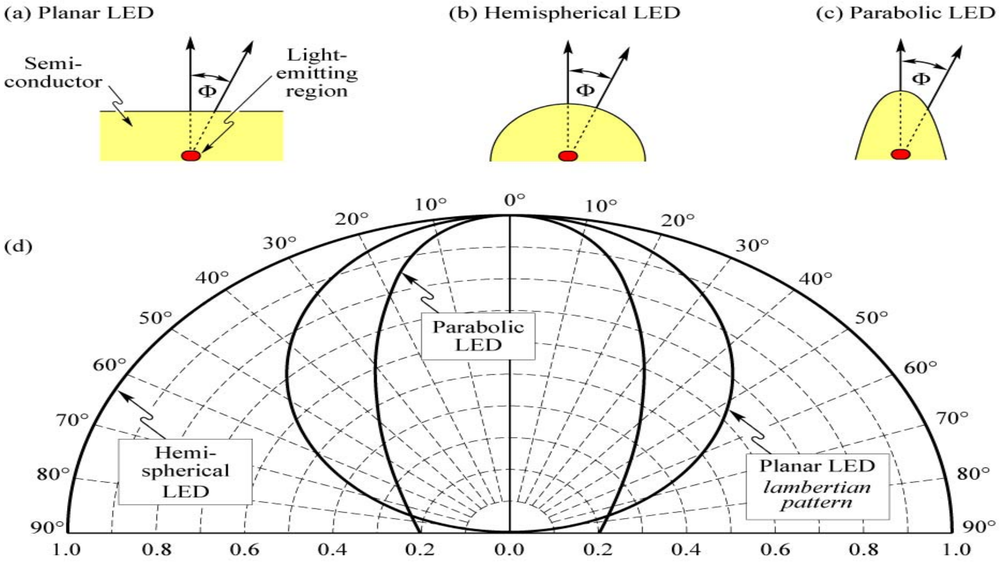
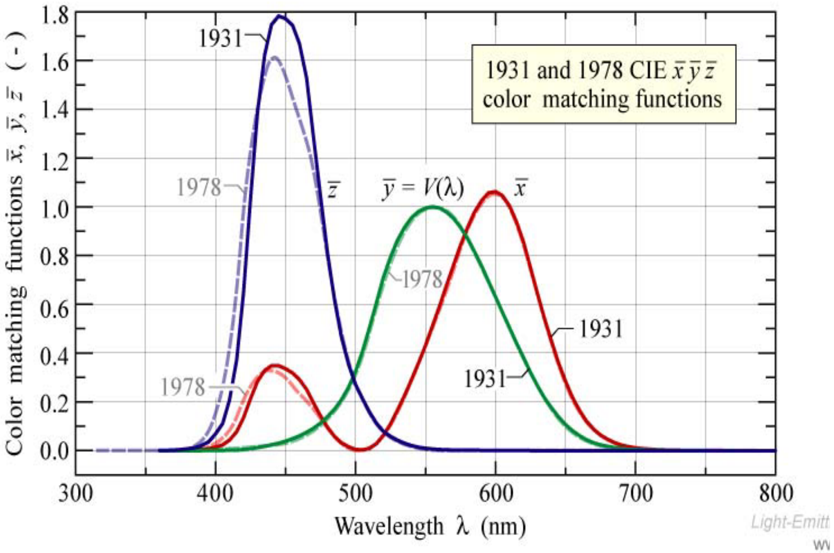


Fig. 5.5. Light-emitting diodes with (a) planar, (b) hemispherical, and (c) parabolic surfaces. (d) Far-field patterns of the different types of LEDs. At an angle of $\Phi = 60°$, the lambertian emission pattern decreases to 50 % of its maximum value occurring at $\Phi = 0°$. The three emission patterns are normalized to unity intensity at $\Phi = 0°$.

View Angle describes the spatial intensity distribution and is the difference between the angles corresponding to 50% of the maximum intensity.

$$\triangle\theta_{0.5} = \theta^{R}_{0.5} - \theta^{L}_{0.5}$$

4. Color matching diagram & CIE Chromaticity diagram

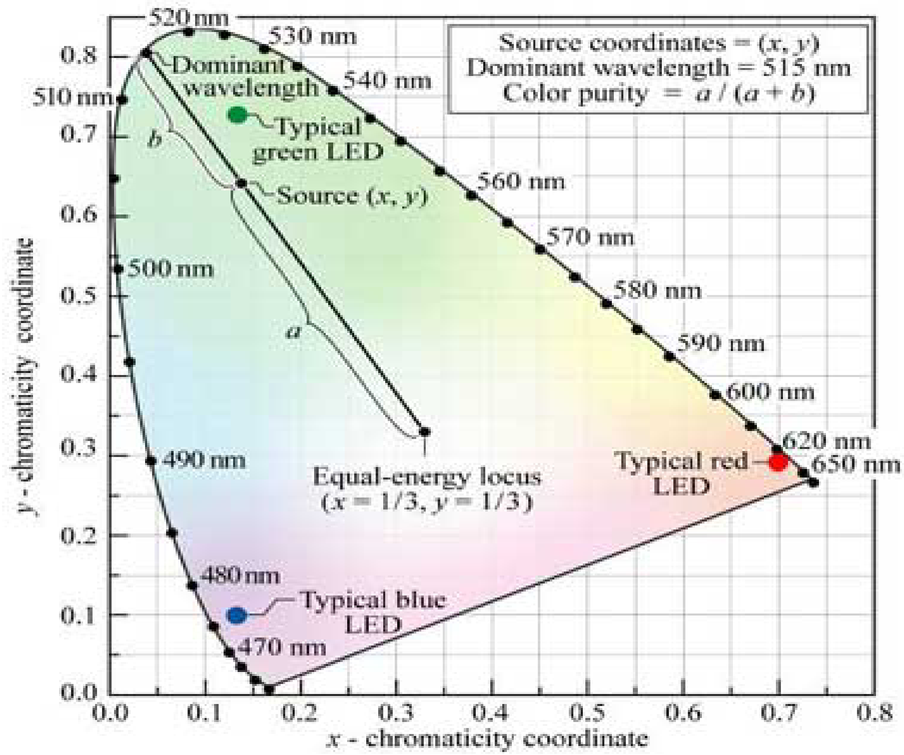


$$X = k\int_{360}^{830} I(\lambda)\bar{x}(\lambda)d\lambda \qquad Y = k\int_{360}^{830} I(\lambda)\bar{y}(\lambda)d\lambda$$

$$Z = k\int_{360}^{830} I(\lambda)\bar{z}(\lambda)d\lambda$$

$$x = \frac{X}{X+Y+Z} \qquad y = \frac{Y}{X+Y+Z}$$

Color mathing diagram

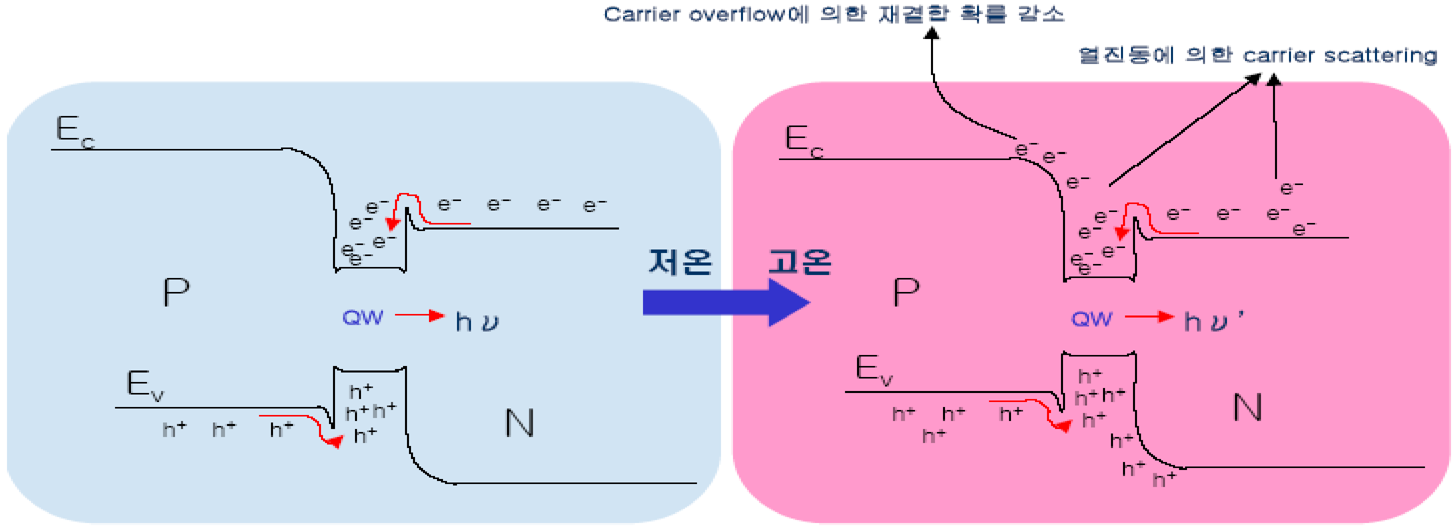


CIE Diagram

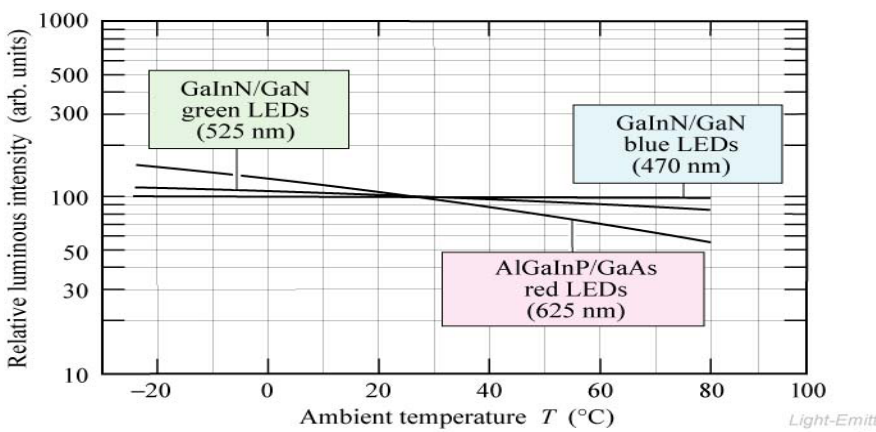
Color purity = a/(a+b)

: color mixing etc…

Temperature dependent



h ν > h ν' 에너지갭의 감소 (발광파장의 증가)



Spectrum of LED

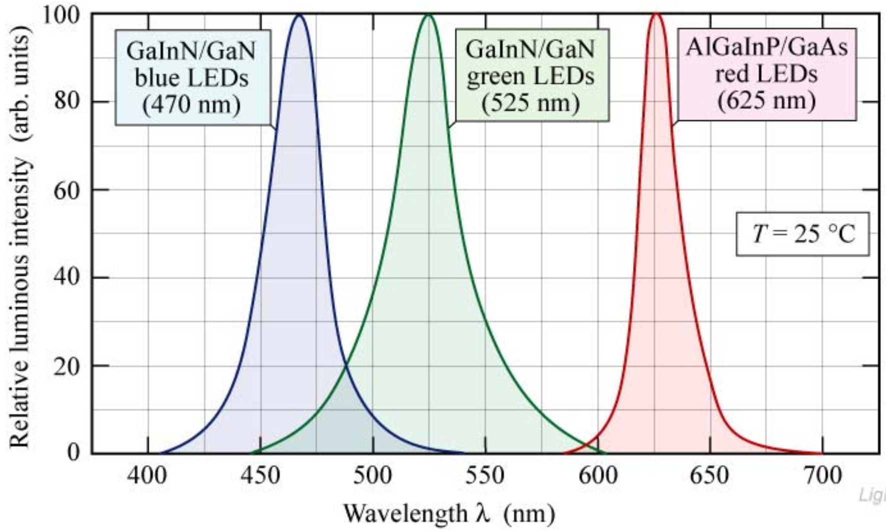
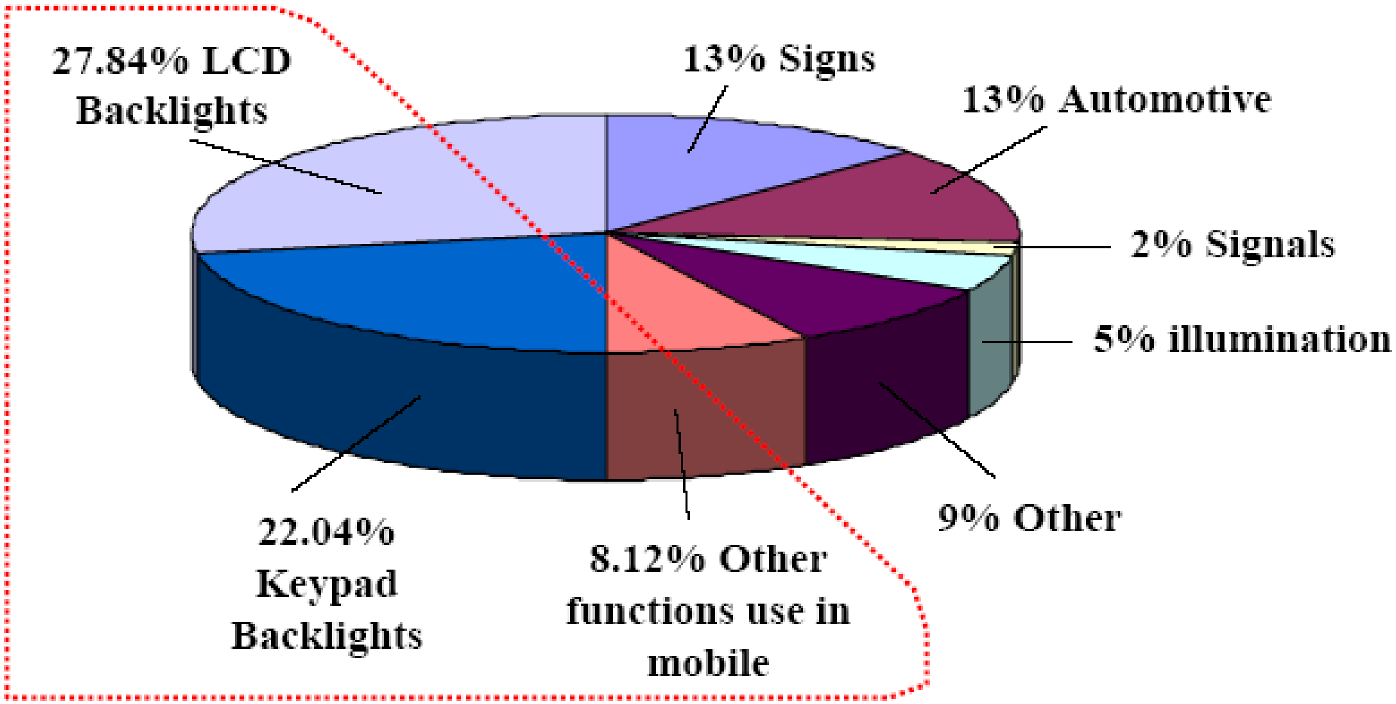


Fig. 12.16. Typical emission spectrum of GaInN/GaN blue, GaInN/GaN green, and AlGaInP/GaAs red LEDs at room temperature (after Toyoda Gosei Corp., 2000).

4. Applications of LED

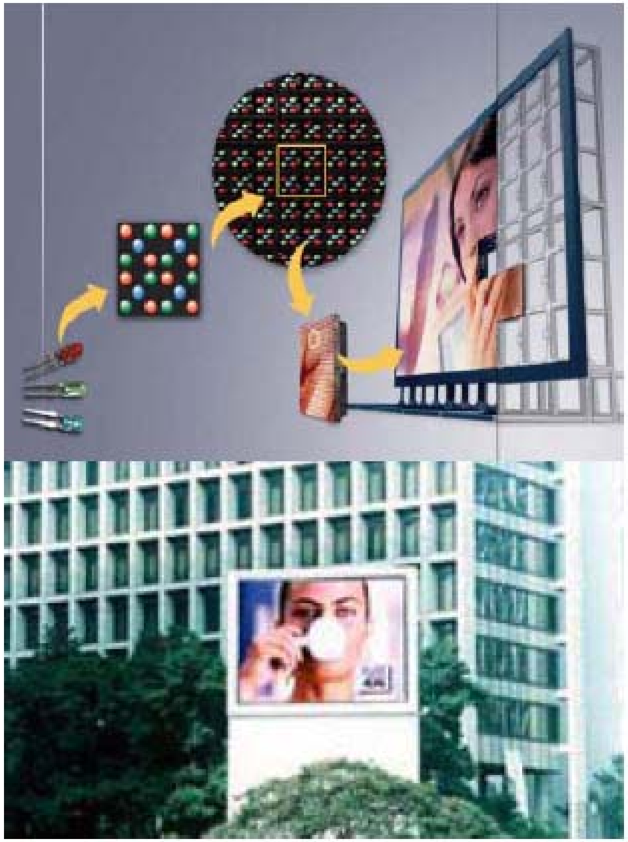
Market of LED

Total: $3.7 billion

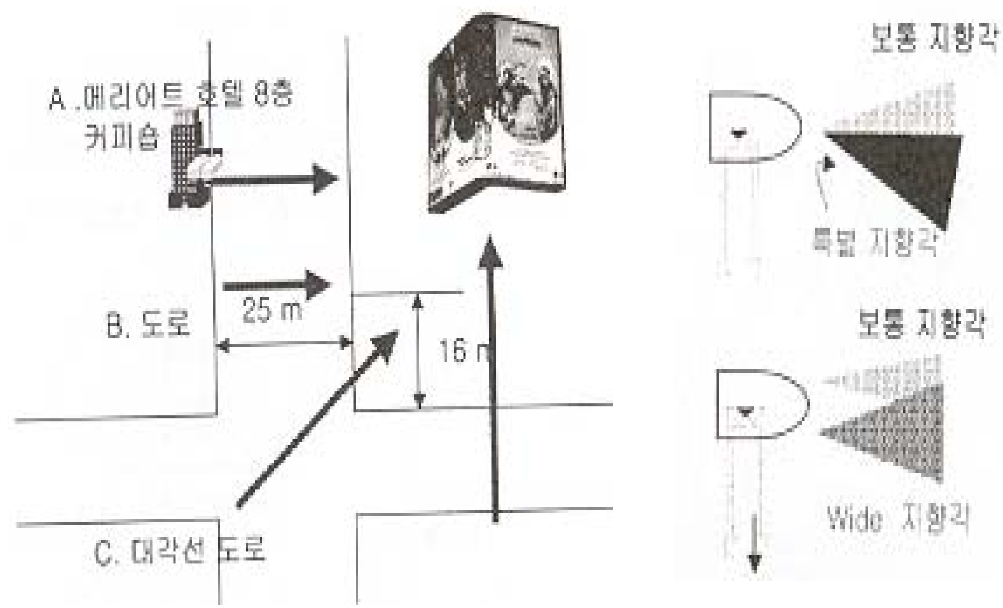


Mobile appliance : 58% total : $2.1 billion

Display & Sign

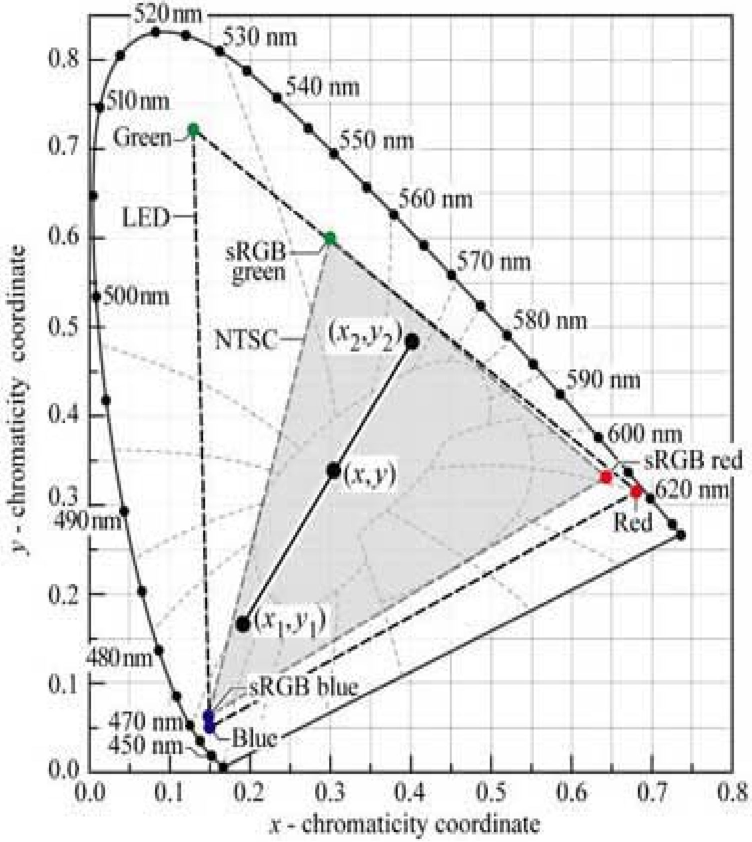


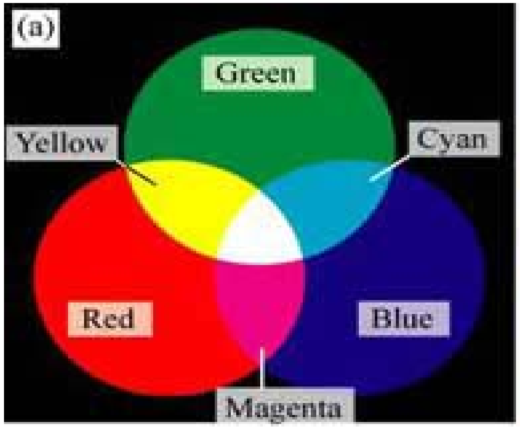
Ex) LED display 성공사례
 장소: 뉴옥 맨하탄 타임 스퀘어 가든 브로드웨이 44번가



LED의 지향각이 10deg down 된 제품사용 건너편 아래 길에서 볼수있게함.
Wide angle 사용. Color mixing이 잘되도록 함

Color mixing





Color Rendering Index

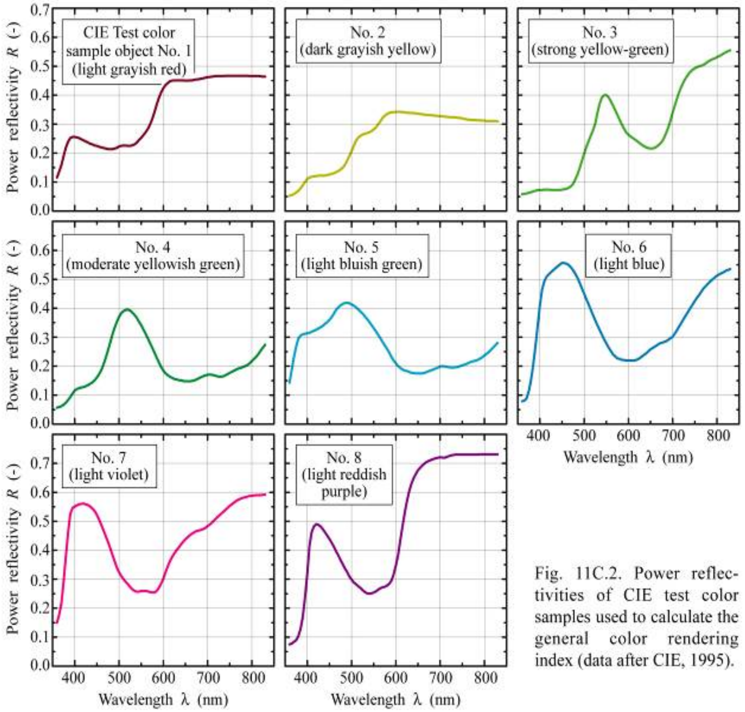


Fig. 11C.2. Power reflectivities of CIE test color samples used to calculate the general color rendering index (data after CIE, 1995).

Ra= (1/8) ∑Ri (i :1~8 : test sample)
= 100 (ideal illuminant)

Courtesy of Prof. T. Taguchi

LED BLU

Back-lighting by LED (Lumileds)

Back-lighting by CCFL

Merit
- High color rendering index
- environment
- No blurring (high response speed)
- No color filter
- High contrast ratio

Demerit
- Heat
- High cost
- color control

Luminous flex per package and lamp price per lumen

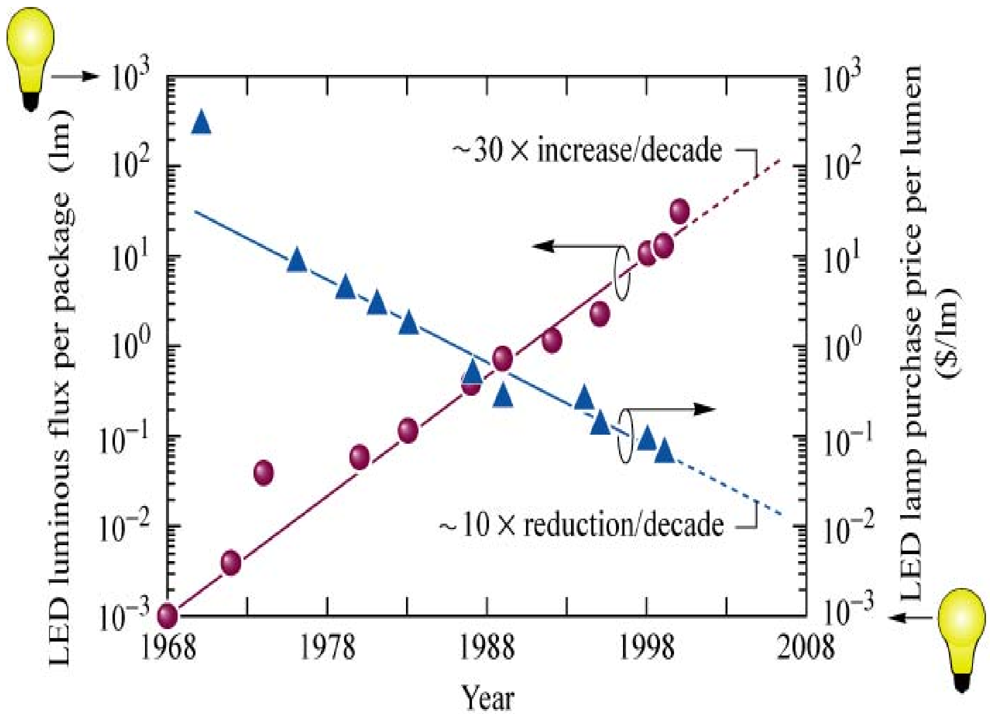


Fig. 12.15. LED luminous flux per package and LED lamp purchase price per lumen versus year. Also shown are the values for a 60 W incandescent tungsten-filament light bulb with a luminous efficiency of ~17 lm/W and a luminous flux of 1000 lm with an approximate price of 1.00 US$ (after Krames *et al.*, 2000).

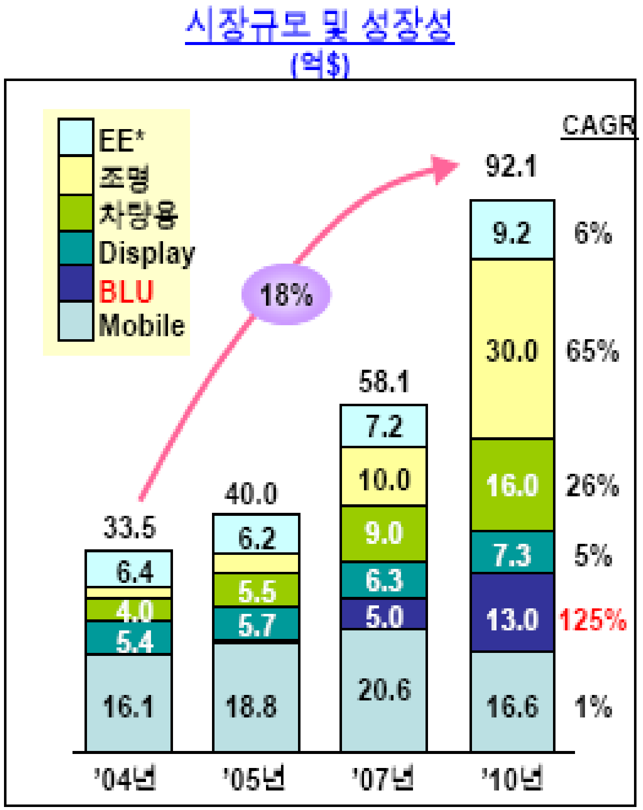
E. F. Schubert
Light-Emitting Diodes (Cambridge Univ. Press)
www.LightEmittingDiodes.org

* 15’ 급 이상 LCD backlight unit 용으로 RGB Multi-chip채용

* 2004년 다수기업에서 시제품 제작
  -소니, 삼성, LG

* 고 연색성 필요로 하는 모니터에 우선 채용
  - 의료용, 그래픽 아트용.
  - CCFL 대비 color gamut 40%넓음

* 문제점- 방열기술, 가격, 색상조절…



*Electronic Equipment

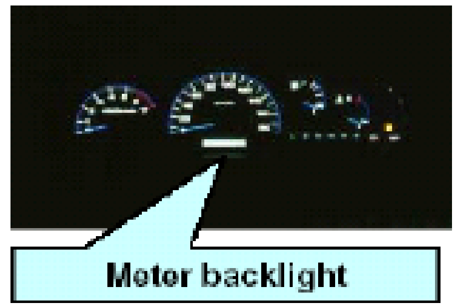
ETC..

Traffic light : low electric power consumption.(~80% of lamp)
long lifetime (10 times)
High brightness (3 times)

Major activity in china
Saturation in USA
지나친 가격경쟁

lamp :

Car : high speed response
high lifetime
freedom of design



Mobile :

Keypad
(Blue,White)

Camera flash

소형 **LCD BLU**

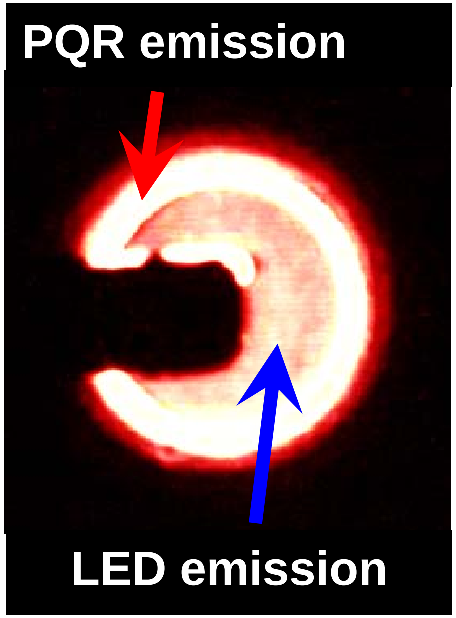
Technical Issue

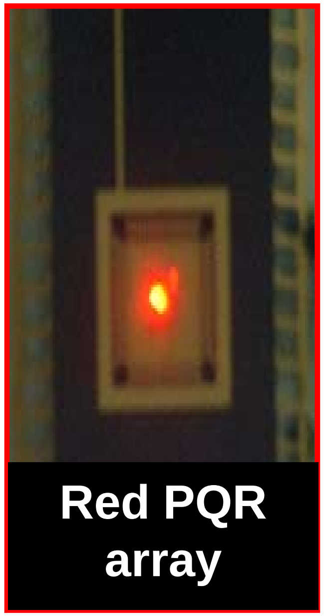
- 제품의소형화, 슬림화가능: 칩사이즈0.3 ~ 2 mm
- ·고속응답: ~ 10^{-8}초on-off 스위칭(백열등= 0.15초)
- ·장수명: 5만~ 100만시간(@30% degradation)
- ·고효율: Up to 55% 외부양자효율
- ·변조가능: Up to 500 Mbps (w/ GI POF @650 nm)
- ·온도에 따른광특성변화(주로적색LED)
- ·저전력소자: 백열등대비15% 소비전력
- ·Cold light : No Infrared radiation

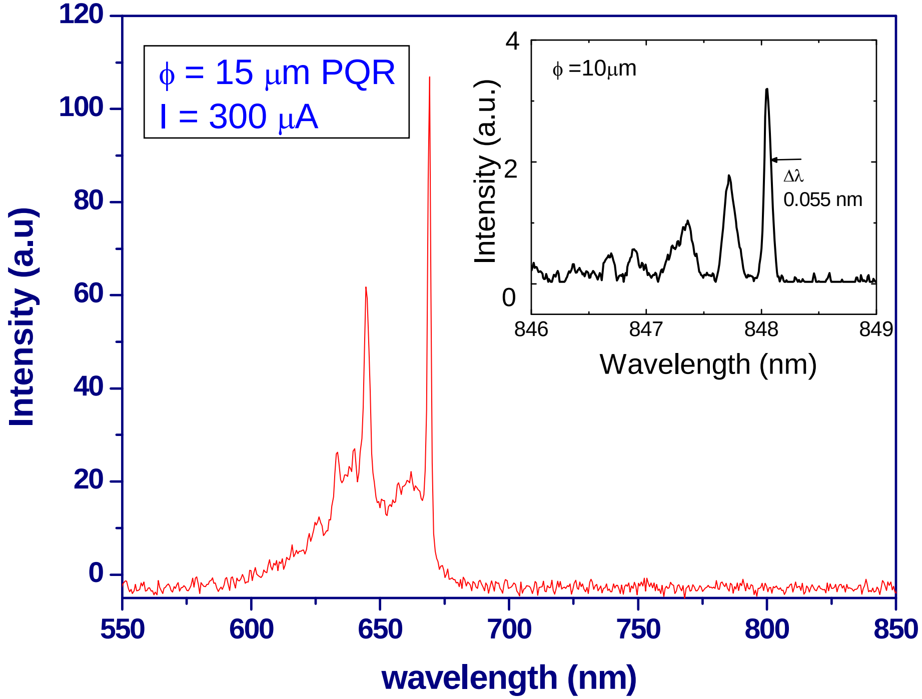
5. PQR

Emission of red (670 nm) PQR laser

Emission images and spectrum of the red PQR laser (670nm)



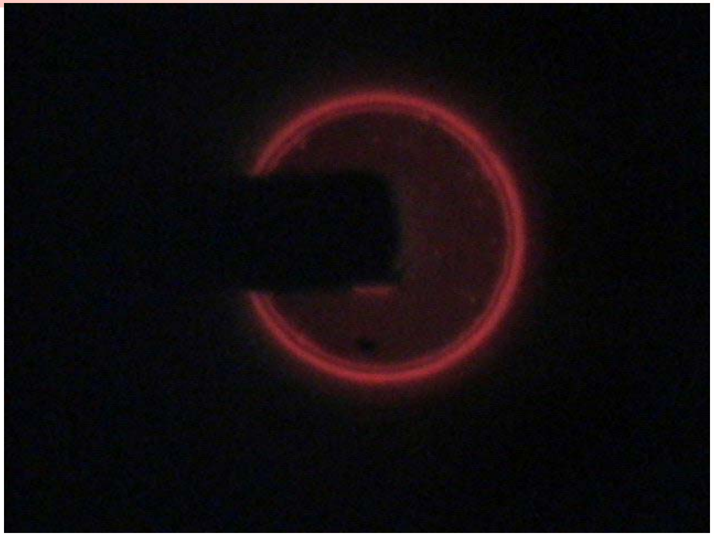




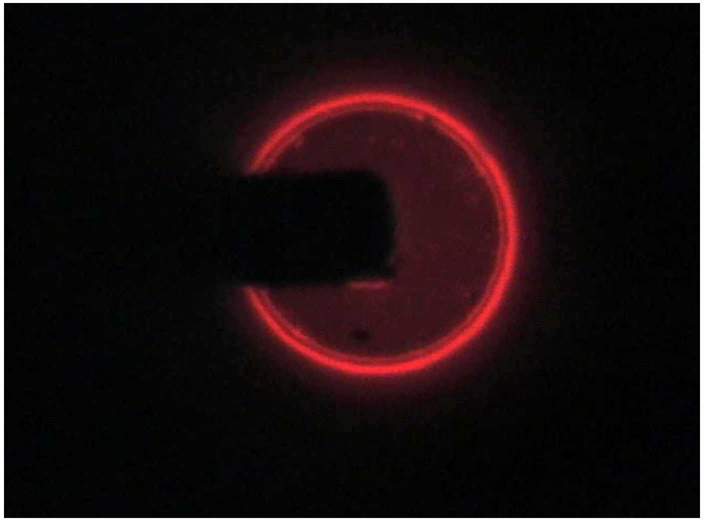
- The PQR lasing region is brighter than the LED emission region, which means very high emission efficiency of the PQR laser.

Red PQR 8x8 array (30 um) emission

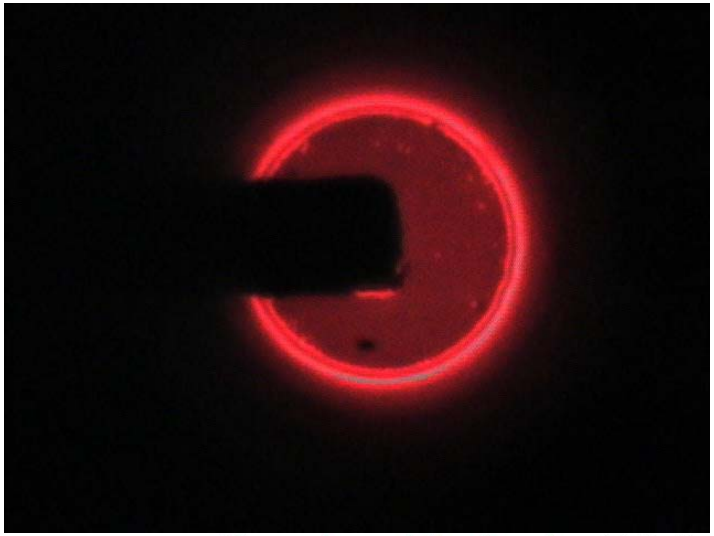
5 uA



10 uA



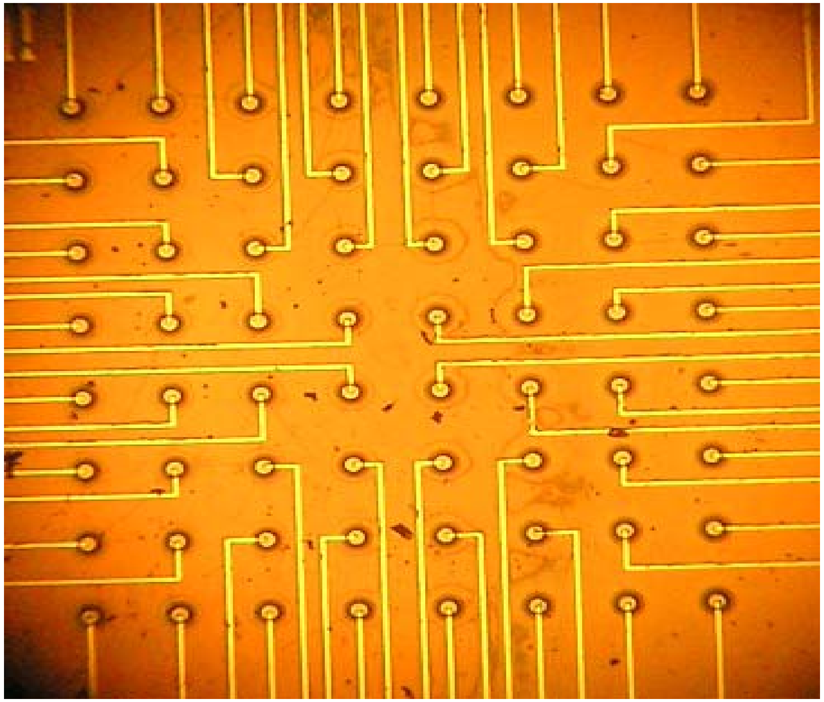
15 uA



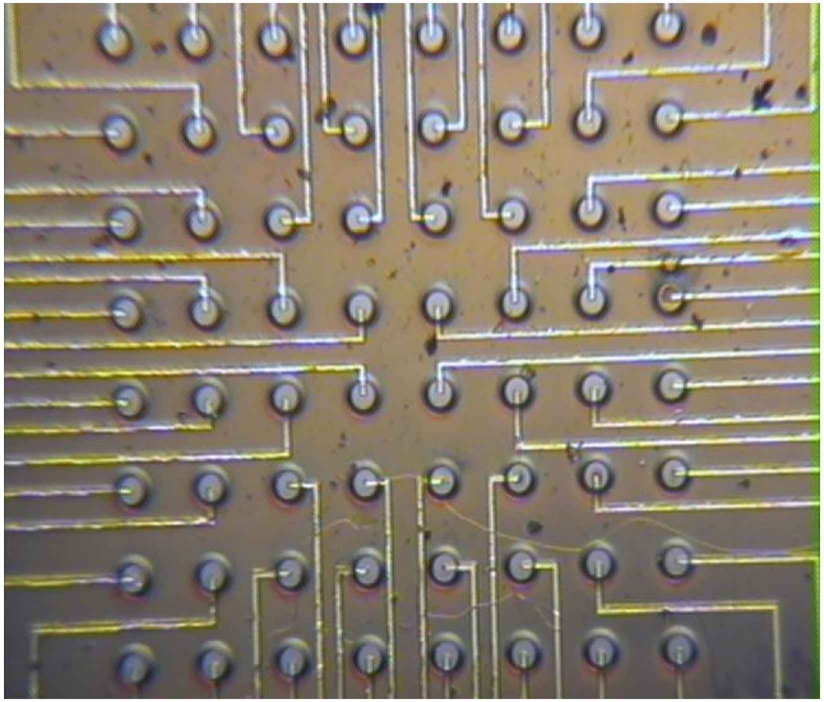
20 uA

POSTECH
Dept. of Electronic & Electrical Eng.

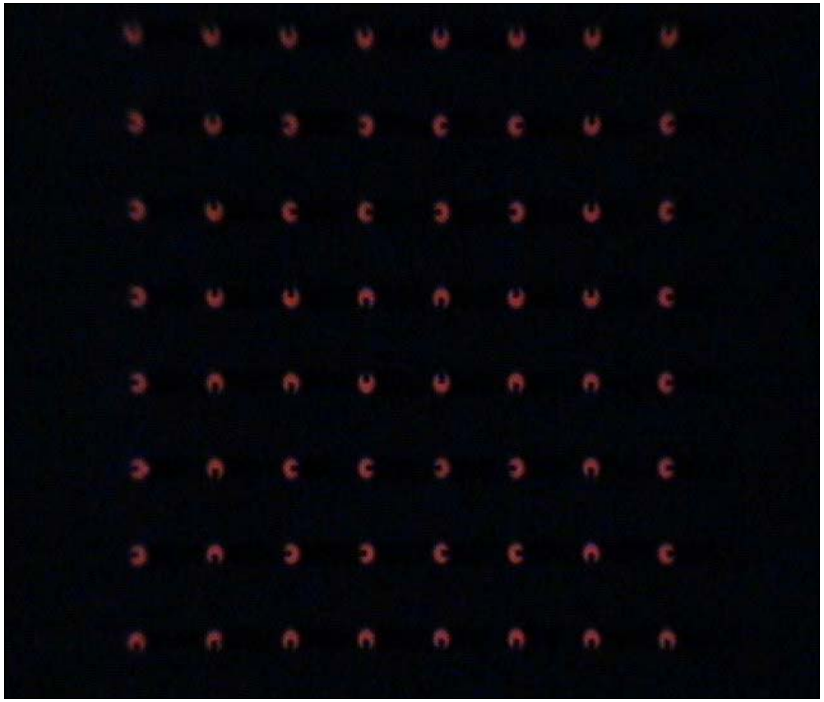
Quantum Photonics IC Design Lab.
---- QPID Lab ----
http://www.postech.ac.kr/ee/light



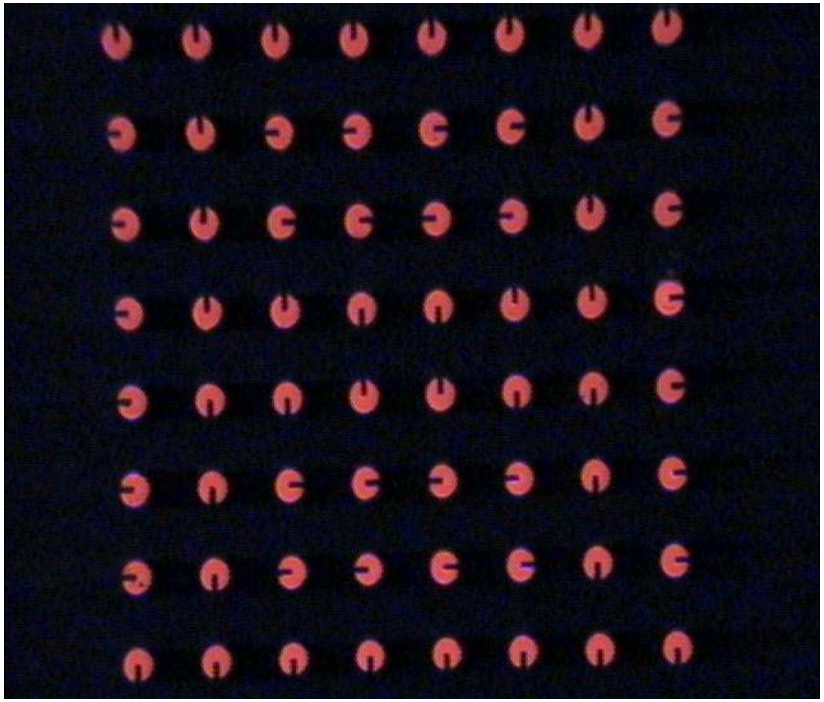
ϕ = 30 μm
I = 0mA (0 μA/cell)



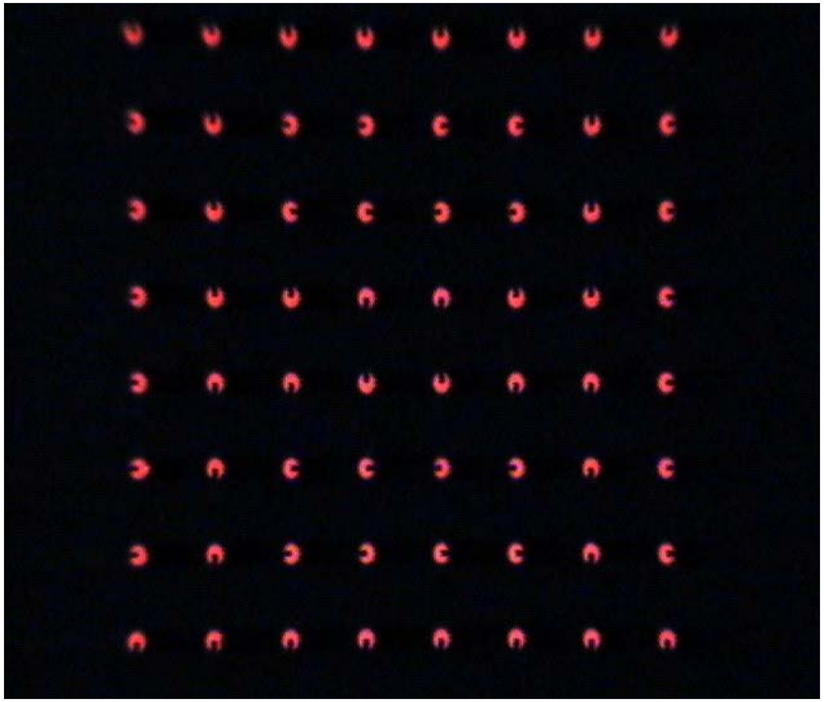
ϕ = 48 μm
I = 0mA (0 μA/cell)



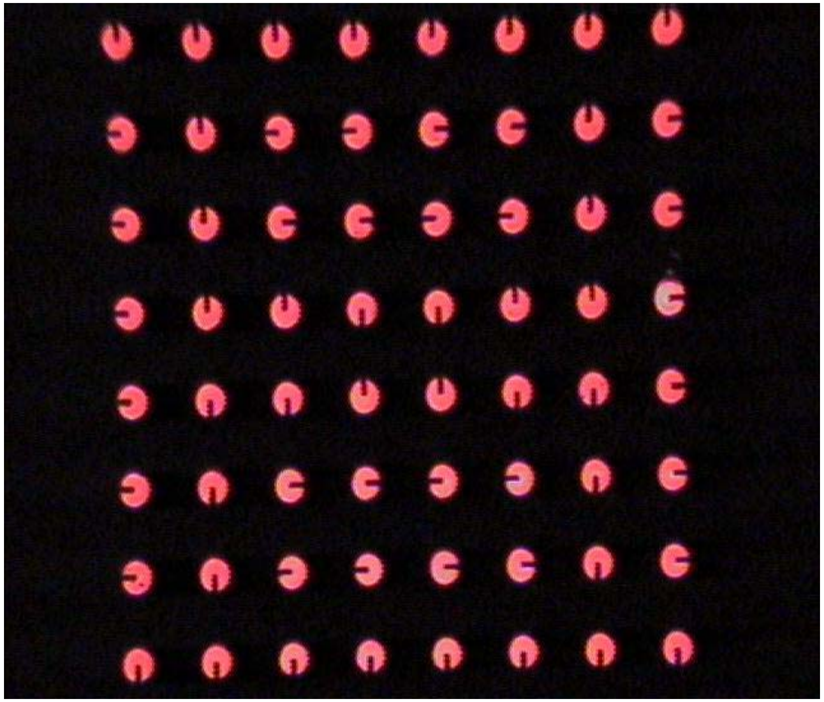
ϕ = 30 μm
I = 1.5 mA (23 μA/cell)



ϕ = 48 μm
I = 1.5 mA (23 μA/cell)

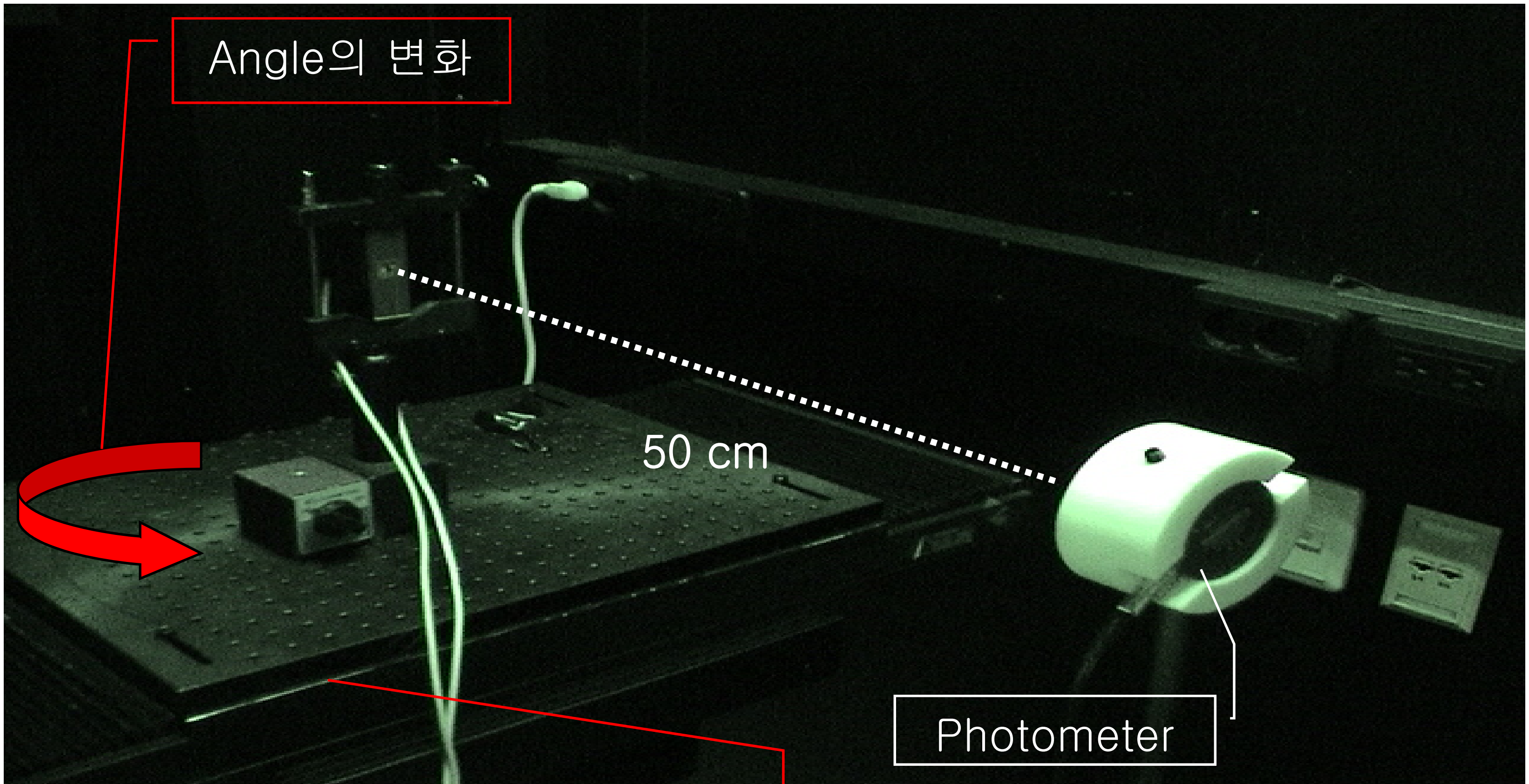


ϕ = 30 μm
I = 2 mA (30 μA/cell)

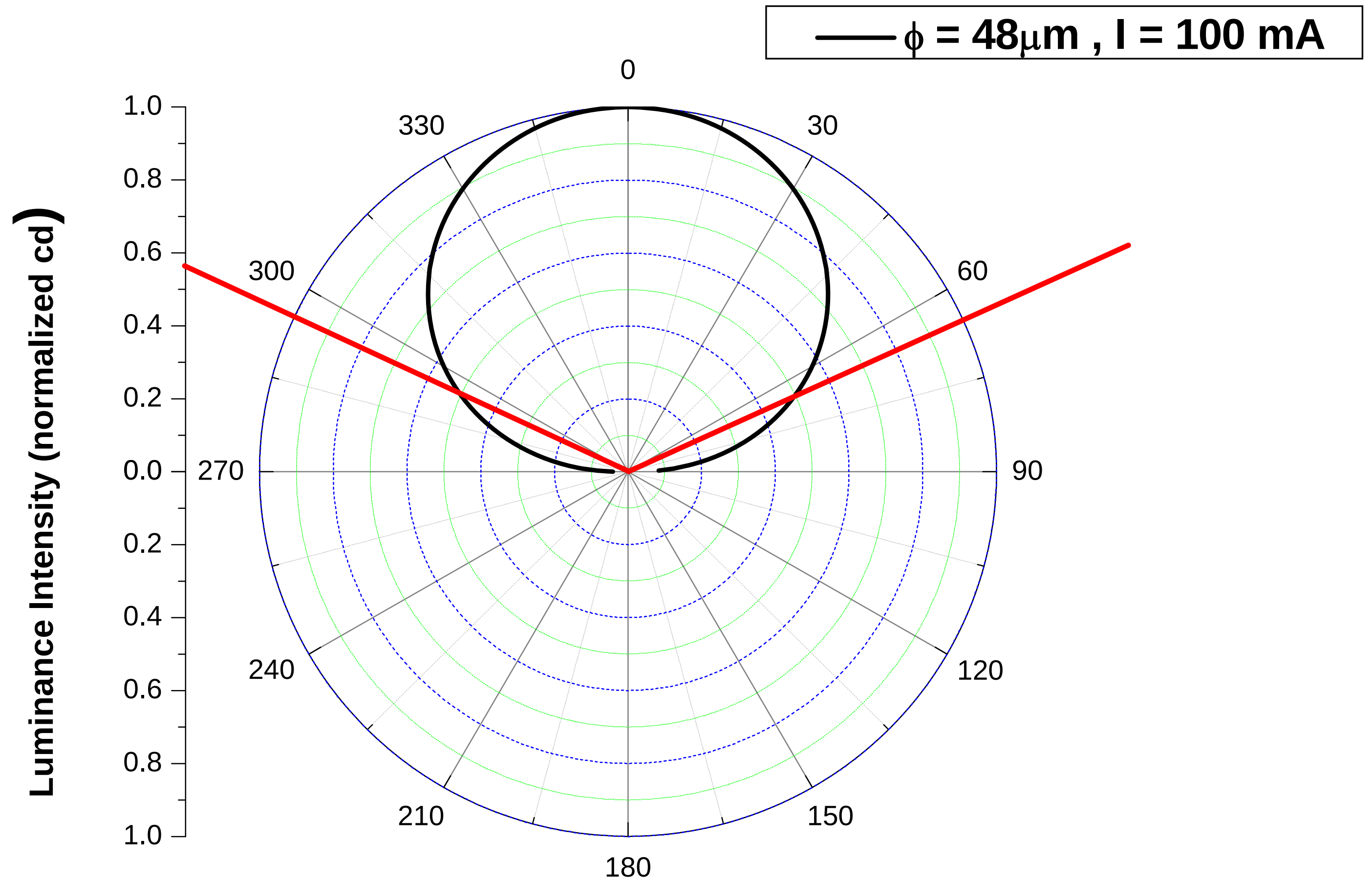


ϕ = 48 μm
I = 2 mA (30 μA/cell)

Luminous Intensity angle dependent (View angle)- Setup

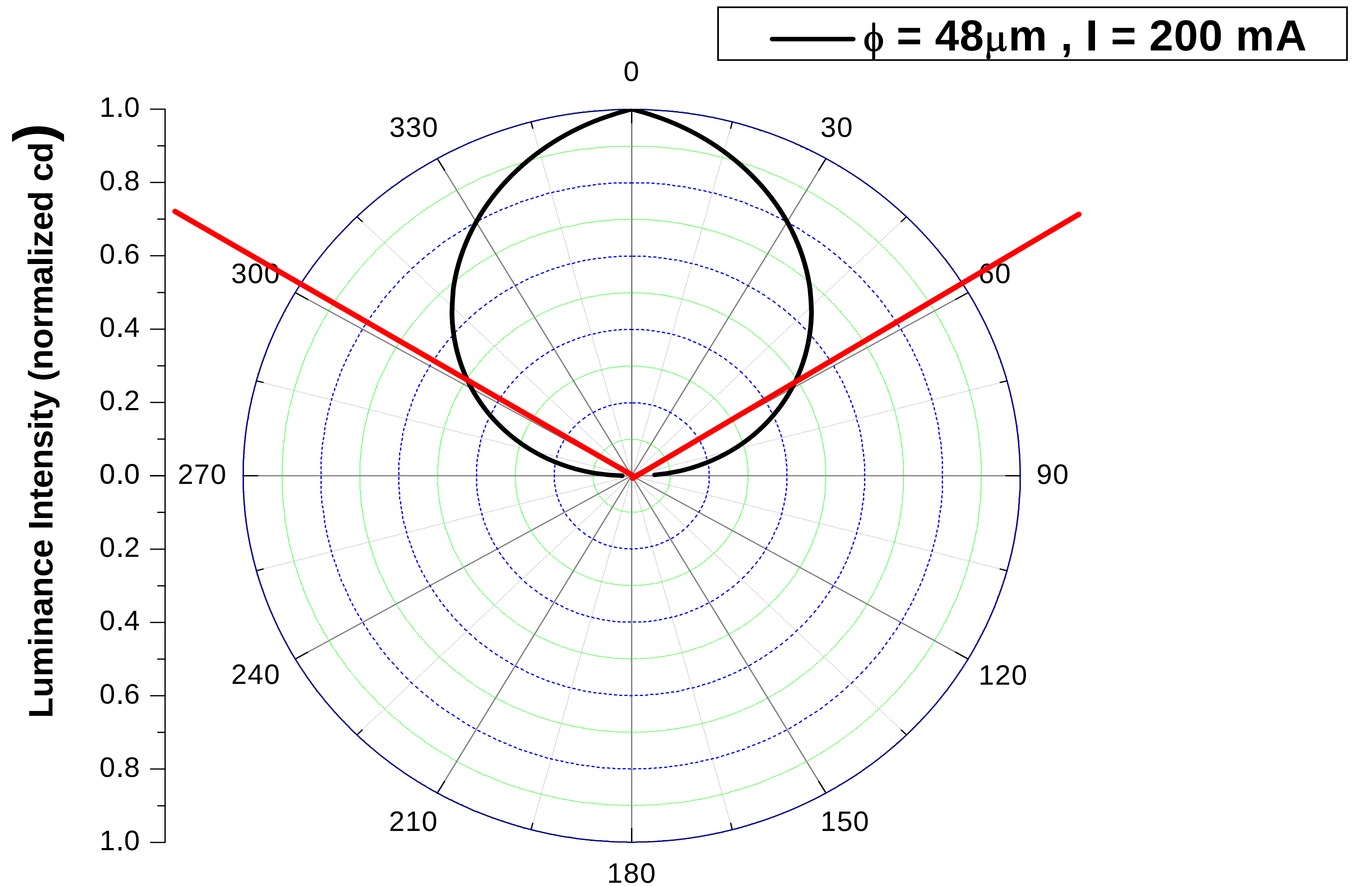


Goniometer (Neo Light 3000)



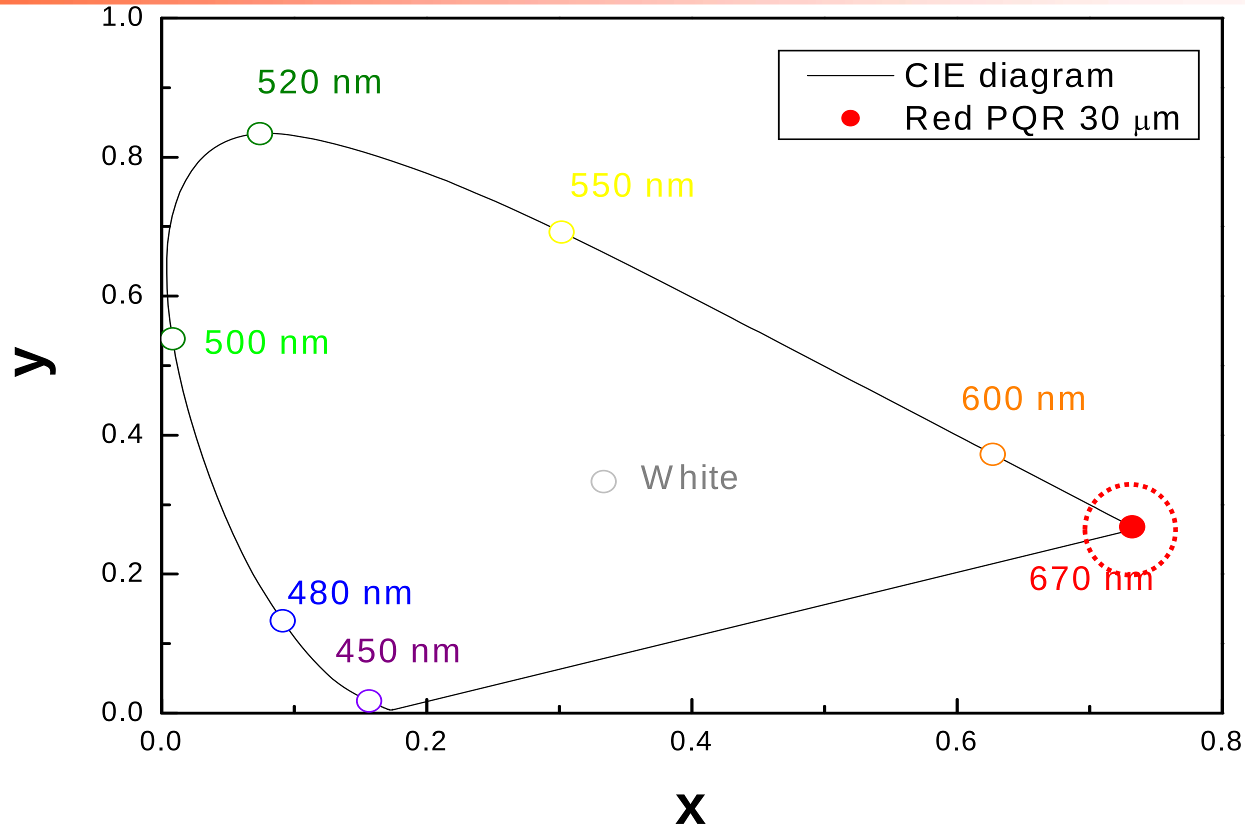
View angle= $\Delta\theta^{R}_{0.5} - \Delta\theta^{L}_{0.5} = 130°$

View angle of Red PQR array (ϕ= 48 μm, 8x8 array)



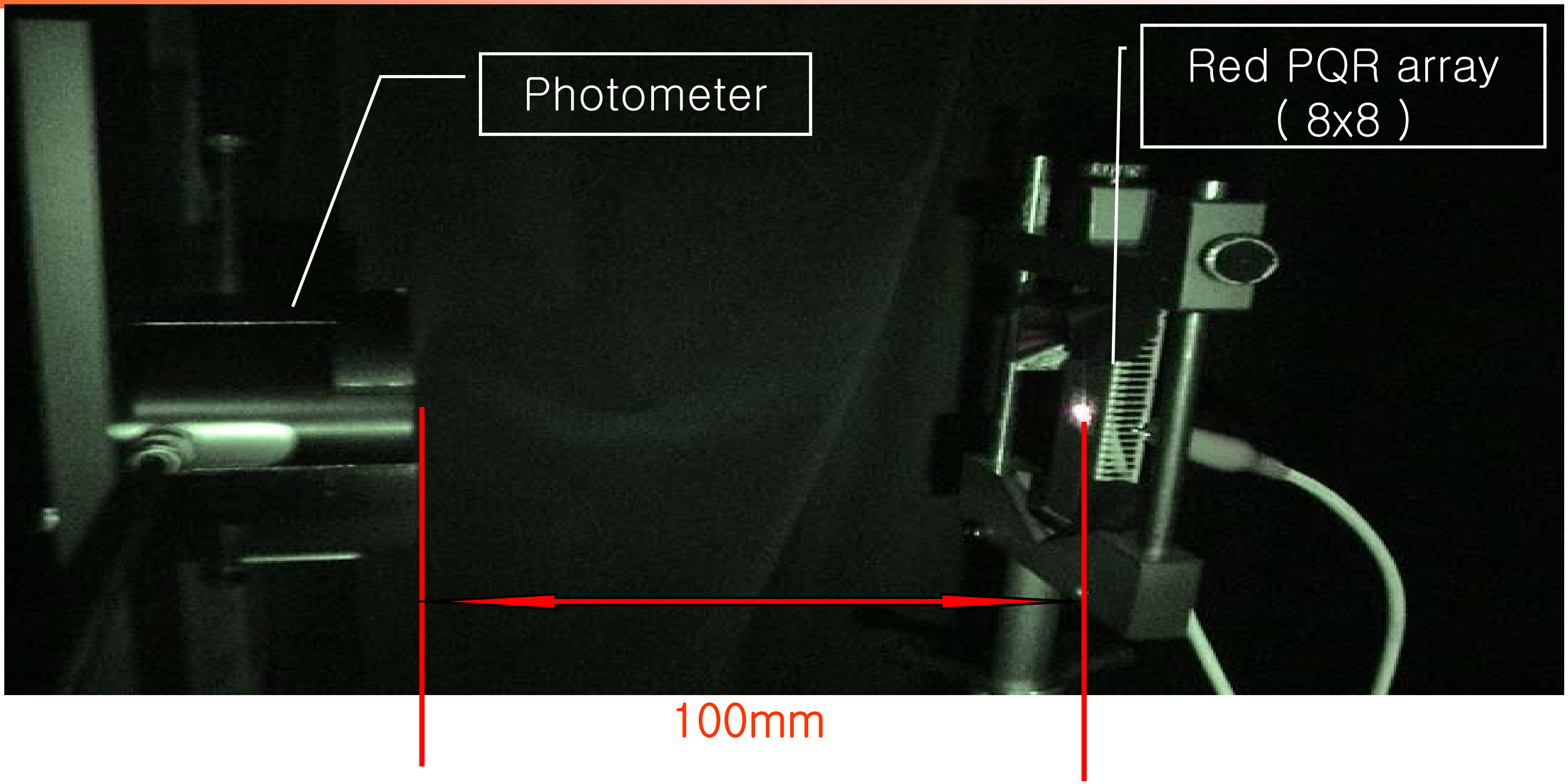
View angle= $\Delta\theta^{R}_{0.5} - \Delta\theta^{L}_{0.5}$ = 118 °

CIE diagram



Color purity : $$\frac{a}{a+b} = \frac{\sqrt{(x - x_{ref})^2 + (y - y_{ref})^2}}{\sqrt{(x_d - x_{ref})^2 + (y_d - y_{ref})^2}} \approx 1$$

Luminance Intensity (Cd)



CIE Standard Condition B

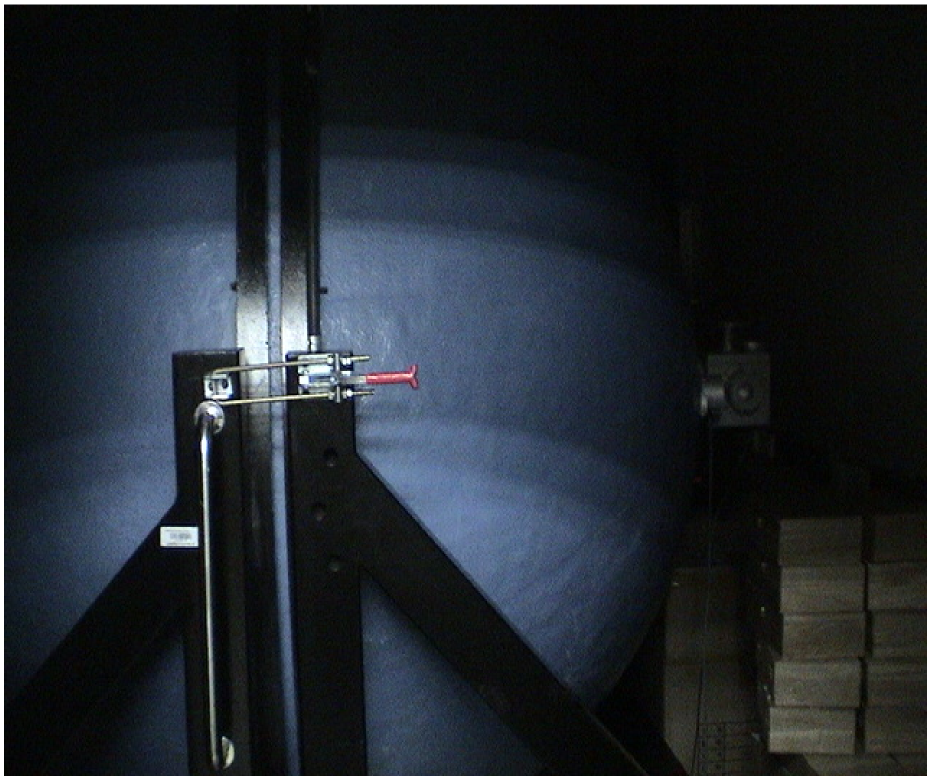
Circular aperture of area : 100mm2
Distance : 100 mm
Equivalent plane angle : 6.5 deg (0.01sr)

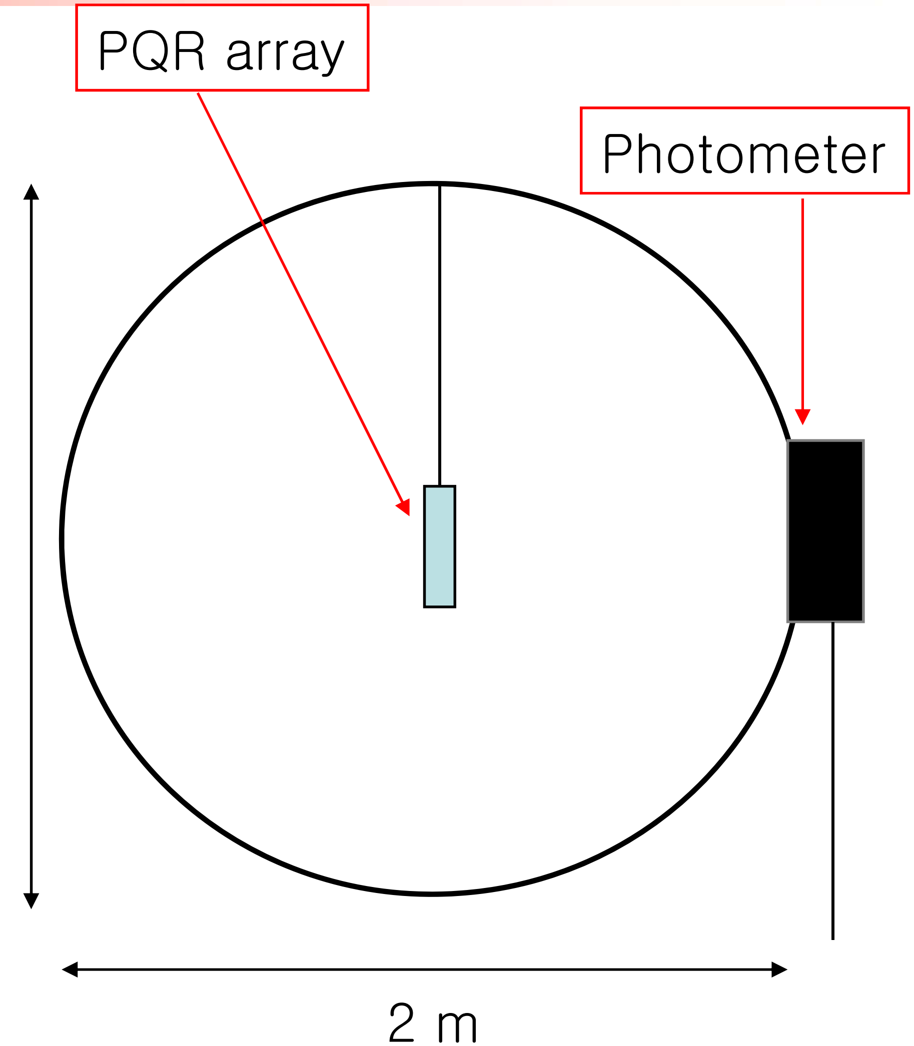
Result

Sample	ϕ= 30 μm $S=4.52 \times 10^{-8} m^2$	ϕ= 48 μm $S=1.15 \times 10^{-7} m^2$
20 mA	2.94 mcd	4.73 mcd
100 mA	23.4 mcd	34.8 mcd
200 mA	43.9 mcd	69.6 mcd

Total luminance flux (lm)

Integrating Sphere (NeoLight PL5000)





Result

Luminance flux	ϕ= 30 μm 0.045m^2	ϕ= 48 μm 0.115m^2
100 mA	18.3 mlm	83.4 mlm
200 mA	90.5 mlm	798 mlm
Luminance efficiency		
100 mA	0.1 lm/w	0.44 lm/w
200 mA	0.23 lm/w	2.018 lm/w

Conventional red LED : 약 620 nm , PQR : 670nm : 시각도 에서 차이
- Conventional LED와 단순비교 어려움

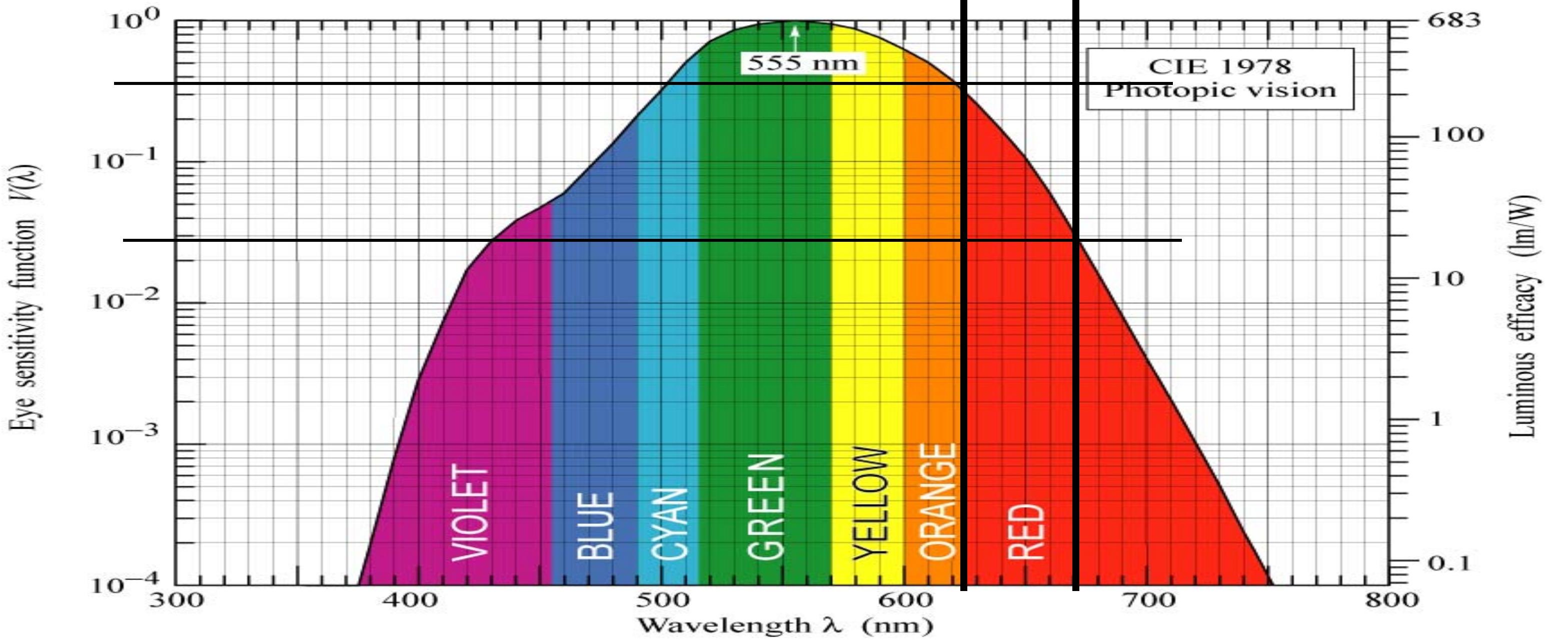


Fig. 16.7. Eye sensitivity function, $V(\lambda)$, (left ordinate) and luminous efficacy, measured in lumens per Watt of optical power (right ordinate). $V(\lambda)$ is greatest at 555 nm. Also given is a polynomial approximation for $V(\lambda)$ (after 1978 CIE data).

E. F. Schubert
Light-Emitting Diodes (Cambridge Univ. Press)
www.LightEmittingDiodes.org

$$\Phi_{lum} = 683 \frac{lm}{W} \int_{\lambda} V(\lambda)\, P(\lambda)\, d\lambda$$