

高功率LED製程技術

Reporter: 黃國瑞

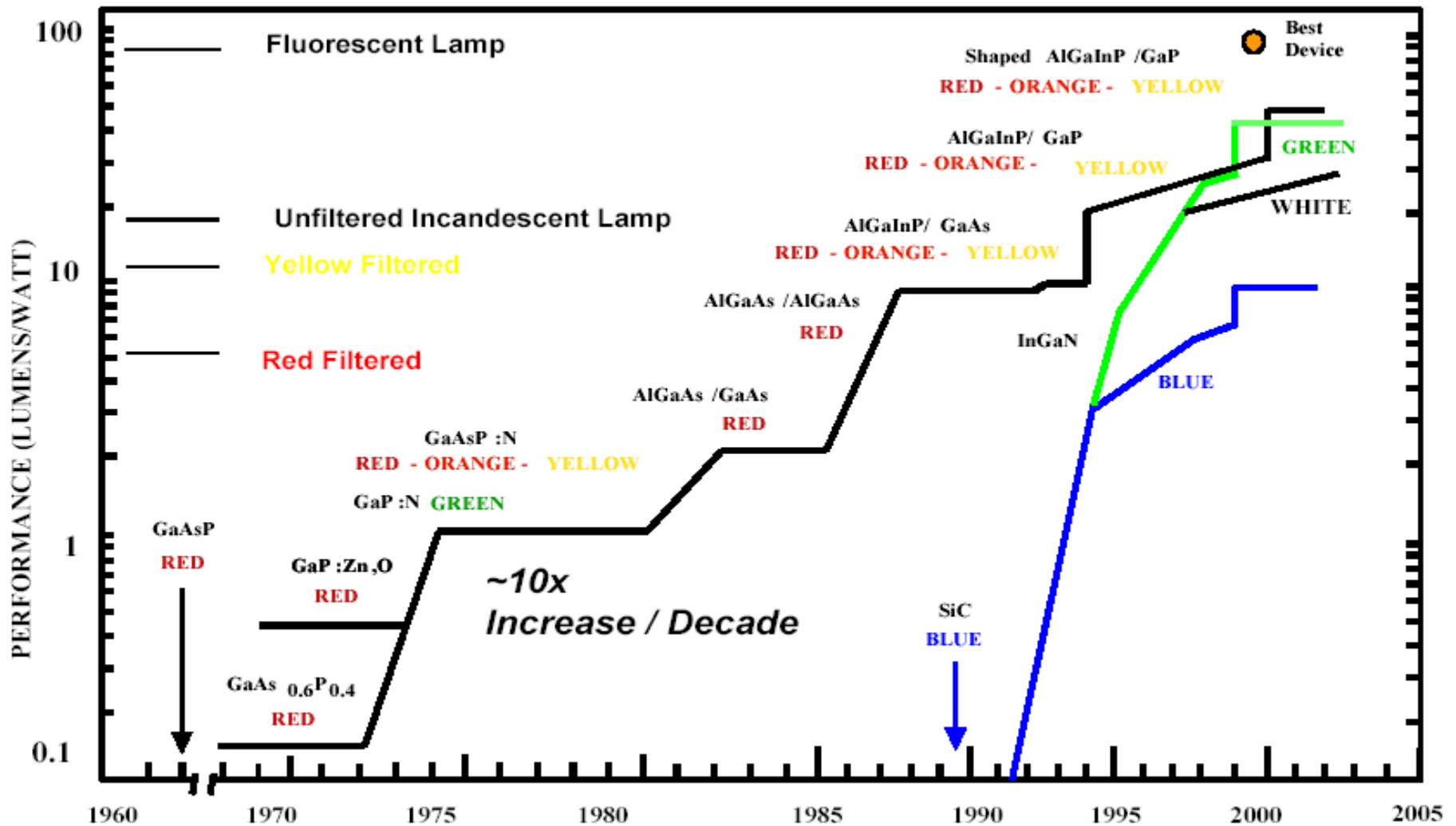
Date: May 11, 2006



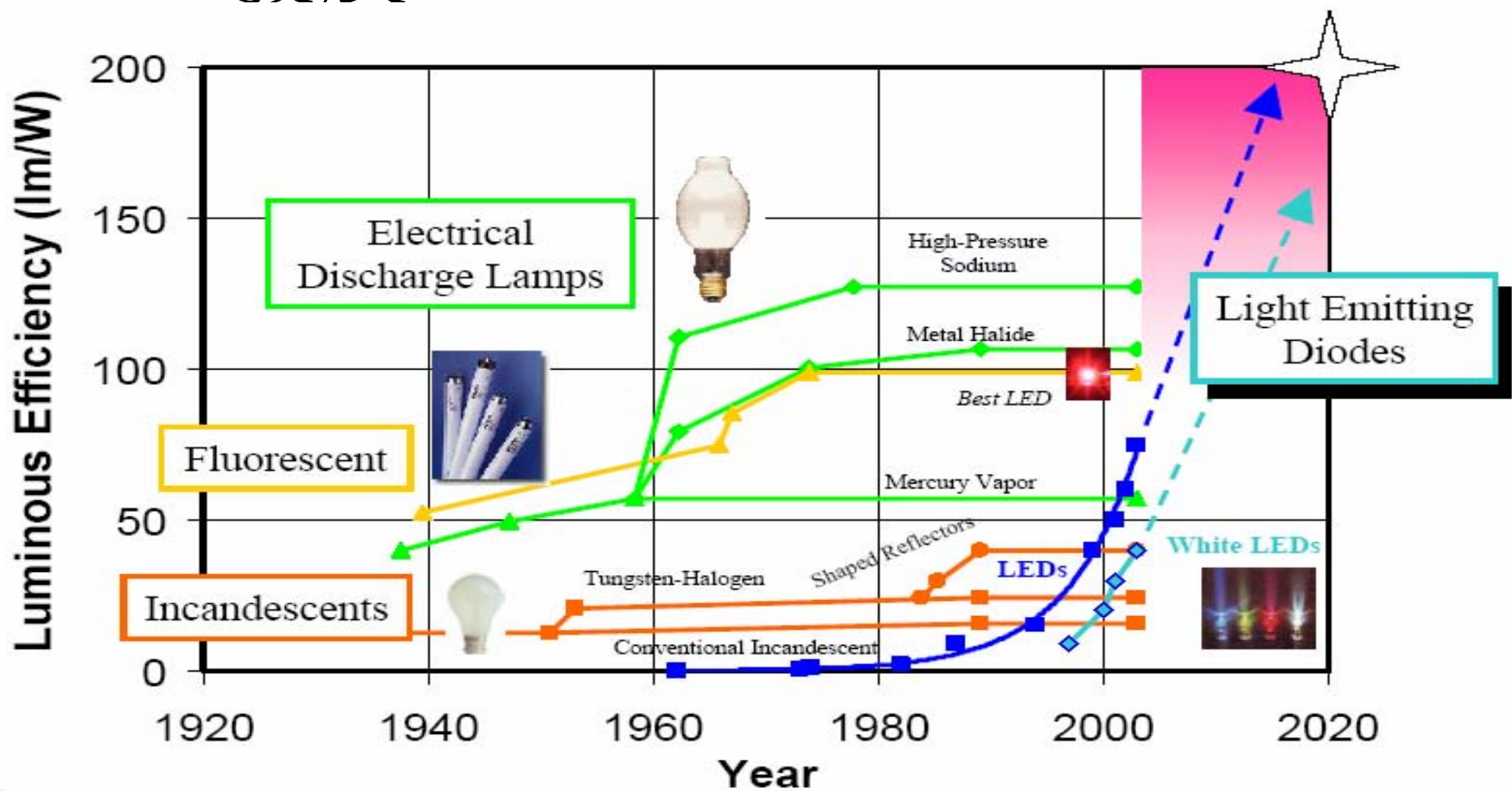
大綱

- 大功率LED的發展
- 大功率LED製程技術
- 大功率LED的可靠度
- 應用與結論

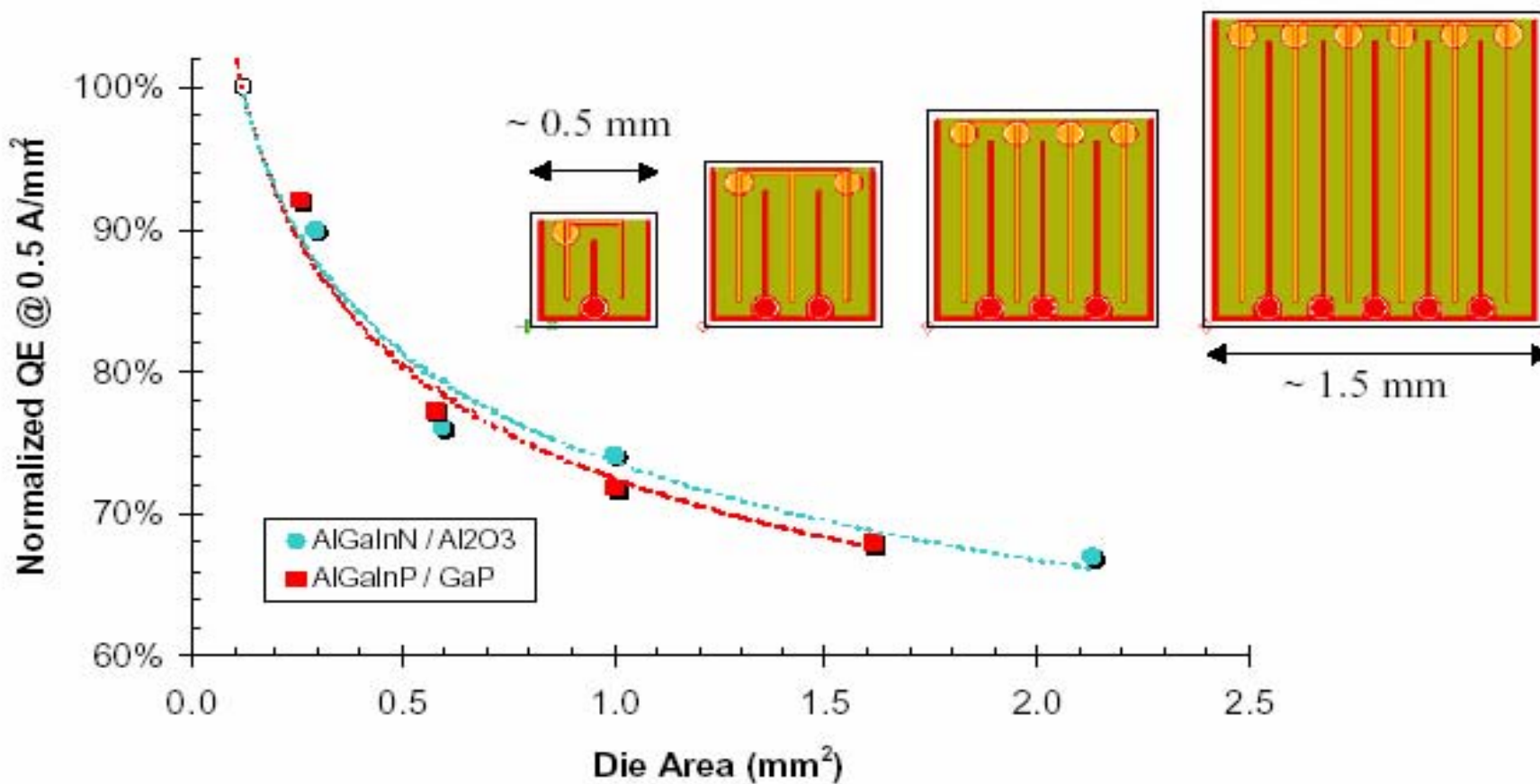
LED 發展



LED 發展



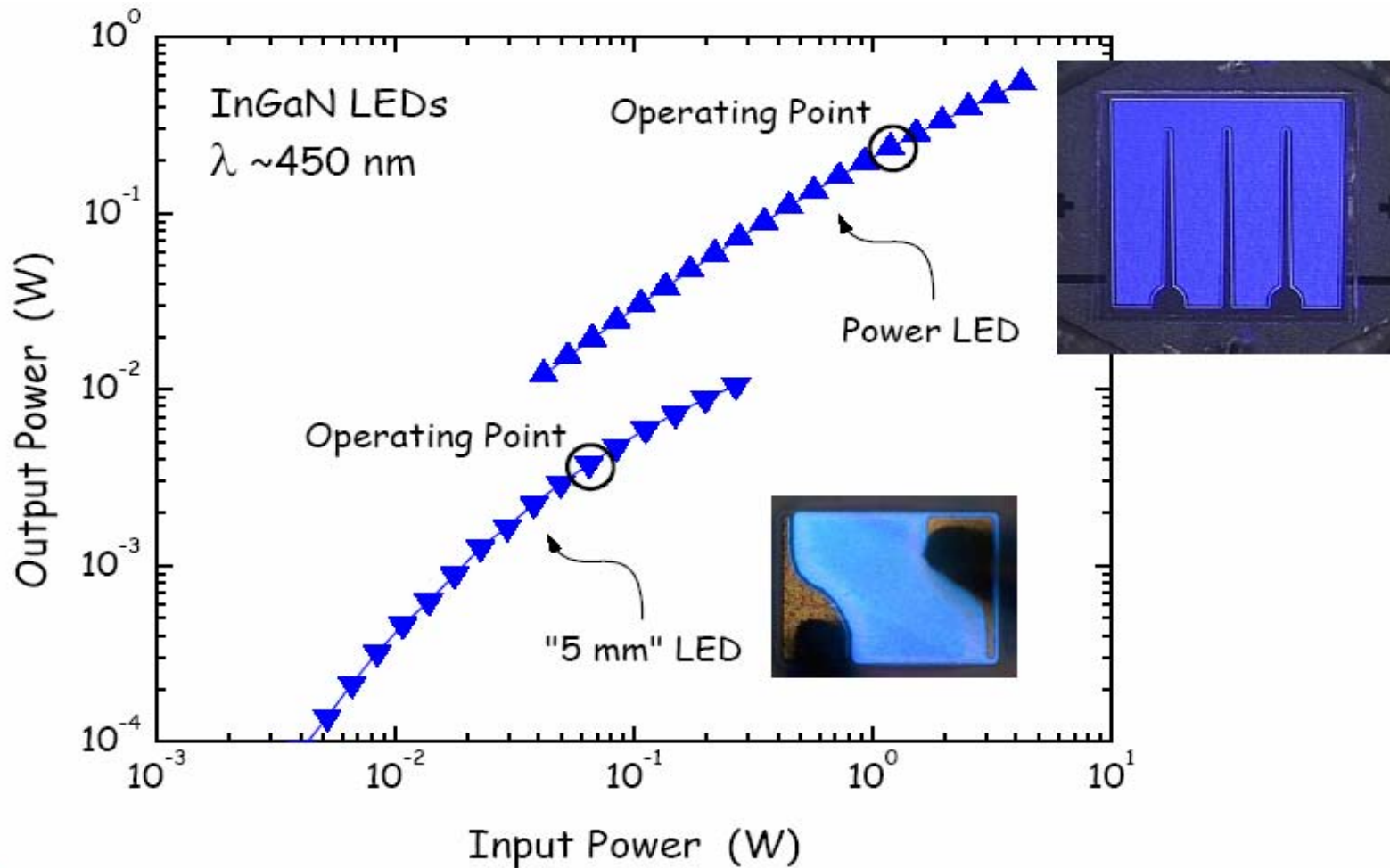
GaN發光效率



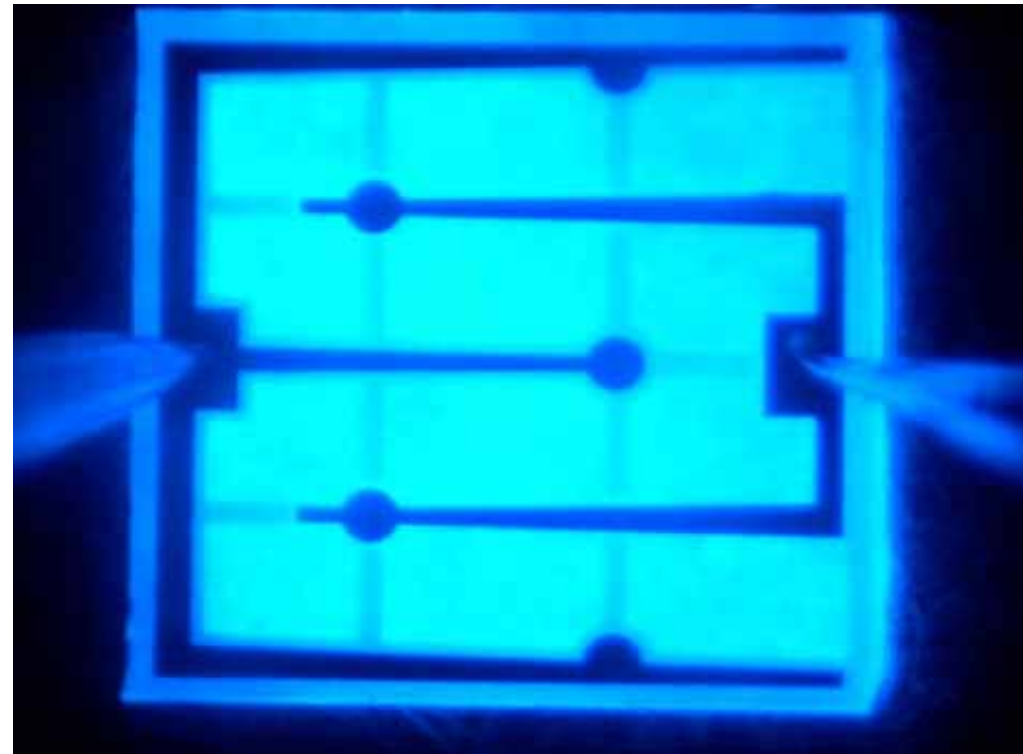
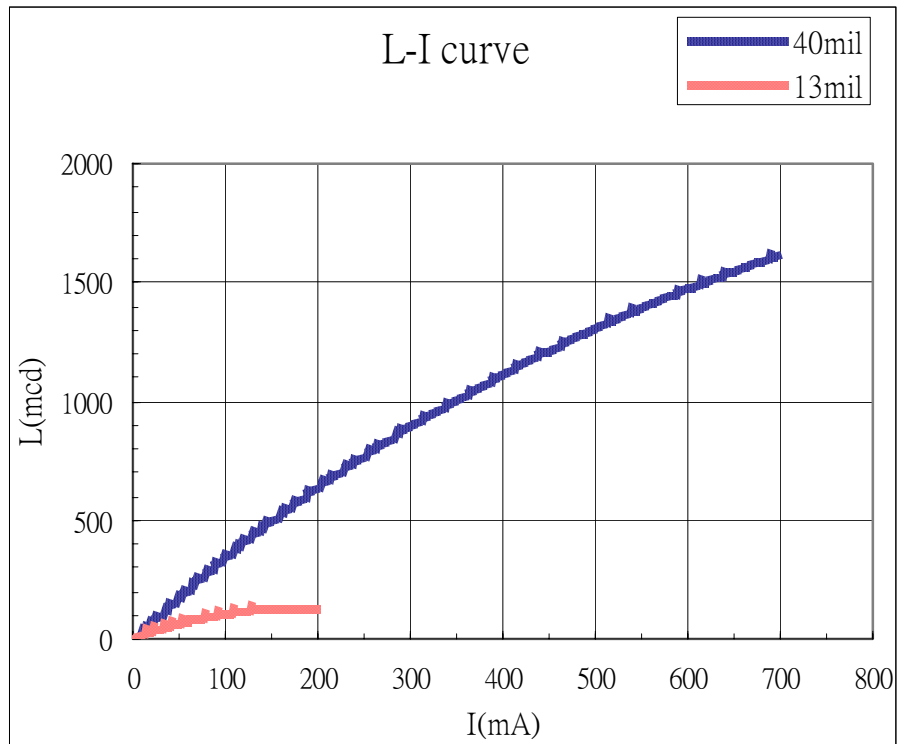
LUMILEDS



Conventional versus Power LED

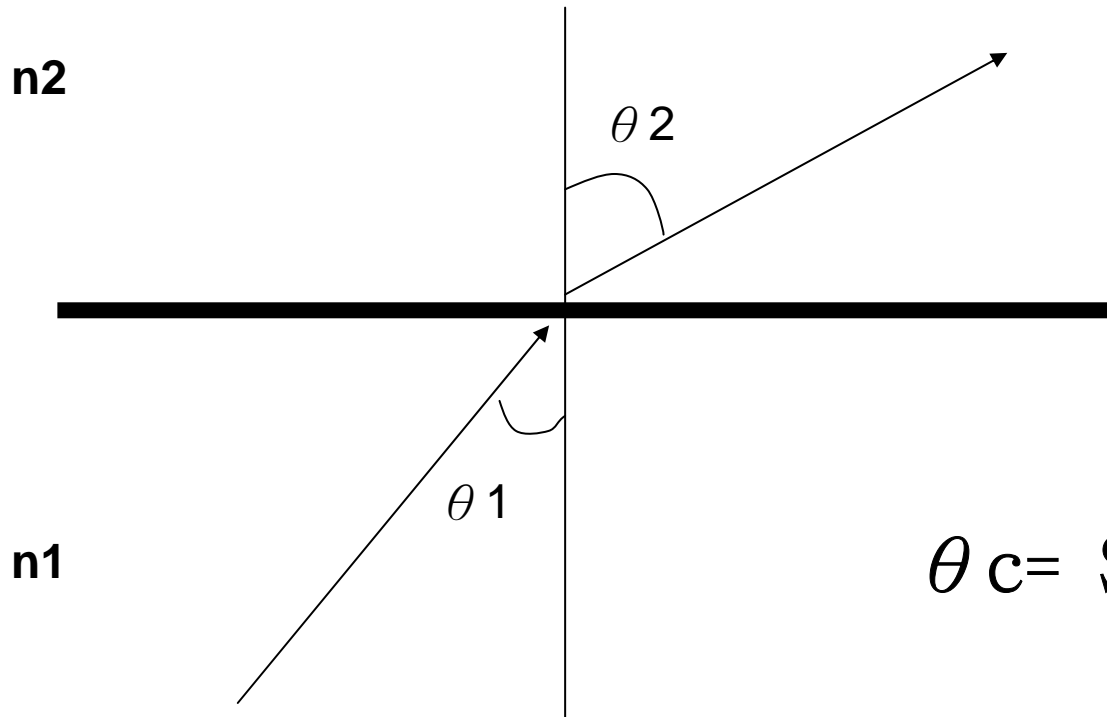


TYNTEK 40 mil Power chip



Snellius Law 全反射臨界角損失

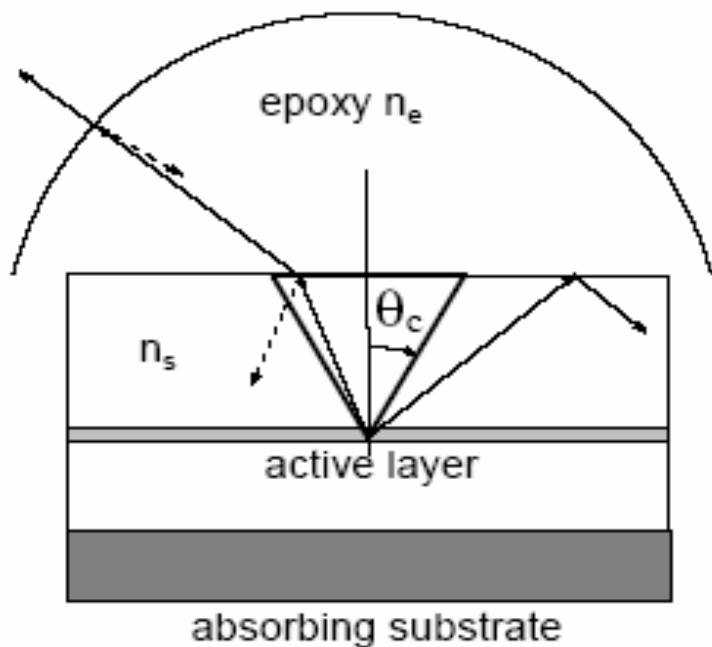
■ $n_1 \sin \theta_1 = n_2 \sin \theta_2$



$$\theta_c = \text{Sin}^{-1}(\theta_2 / \theta_1)$$

Light Extraction

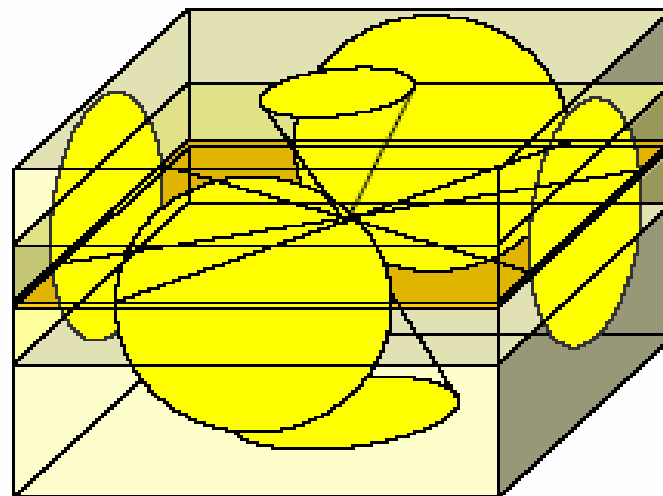
Absorbing substrate



GaN:22°

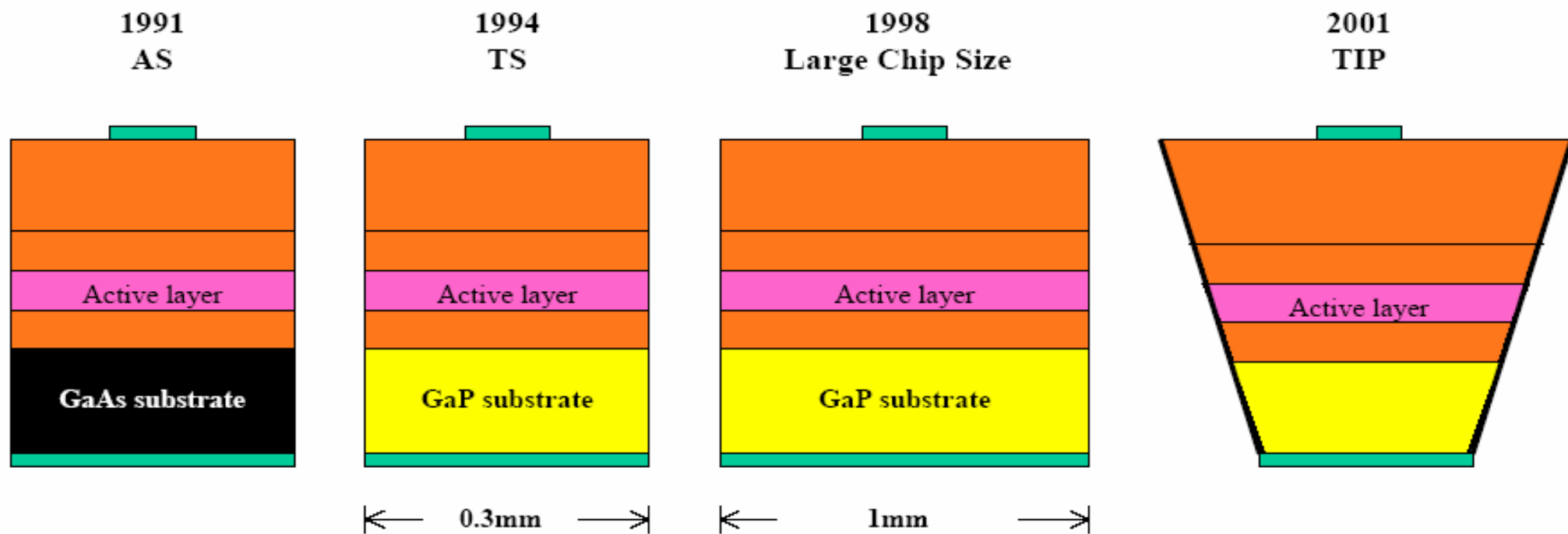
AlGaAs=17°

Transparent substrate



From A. Žukauskas *et al.*, *MRS Bull.* 26, 764, 2001.

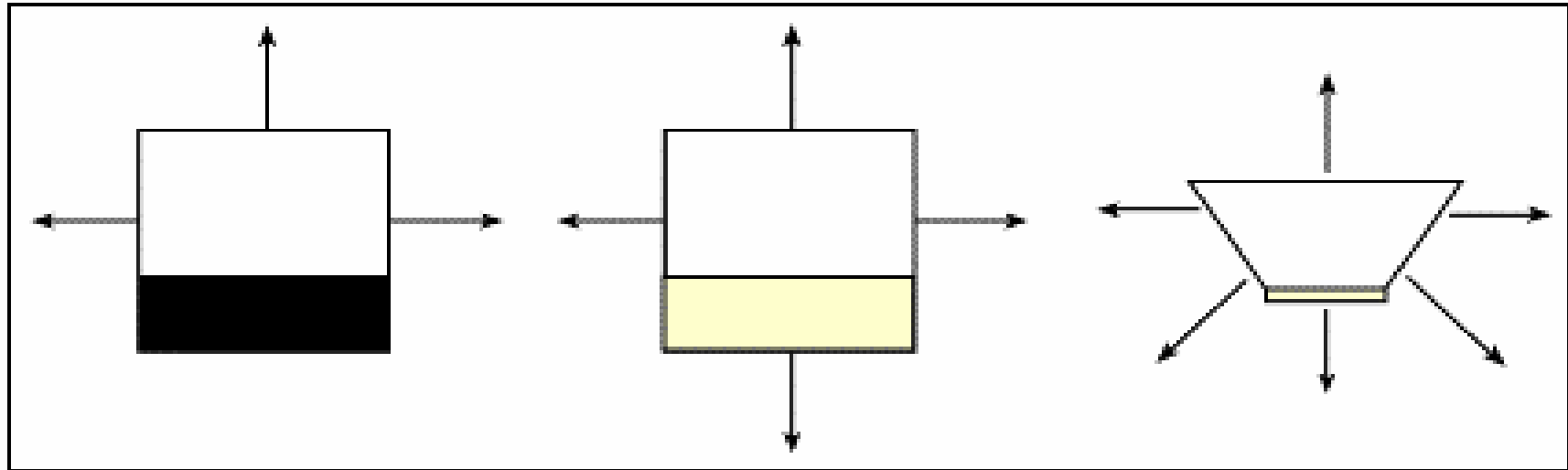
Lumileds AlGaInP LED



增加光取出效率

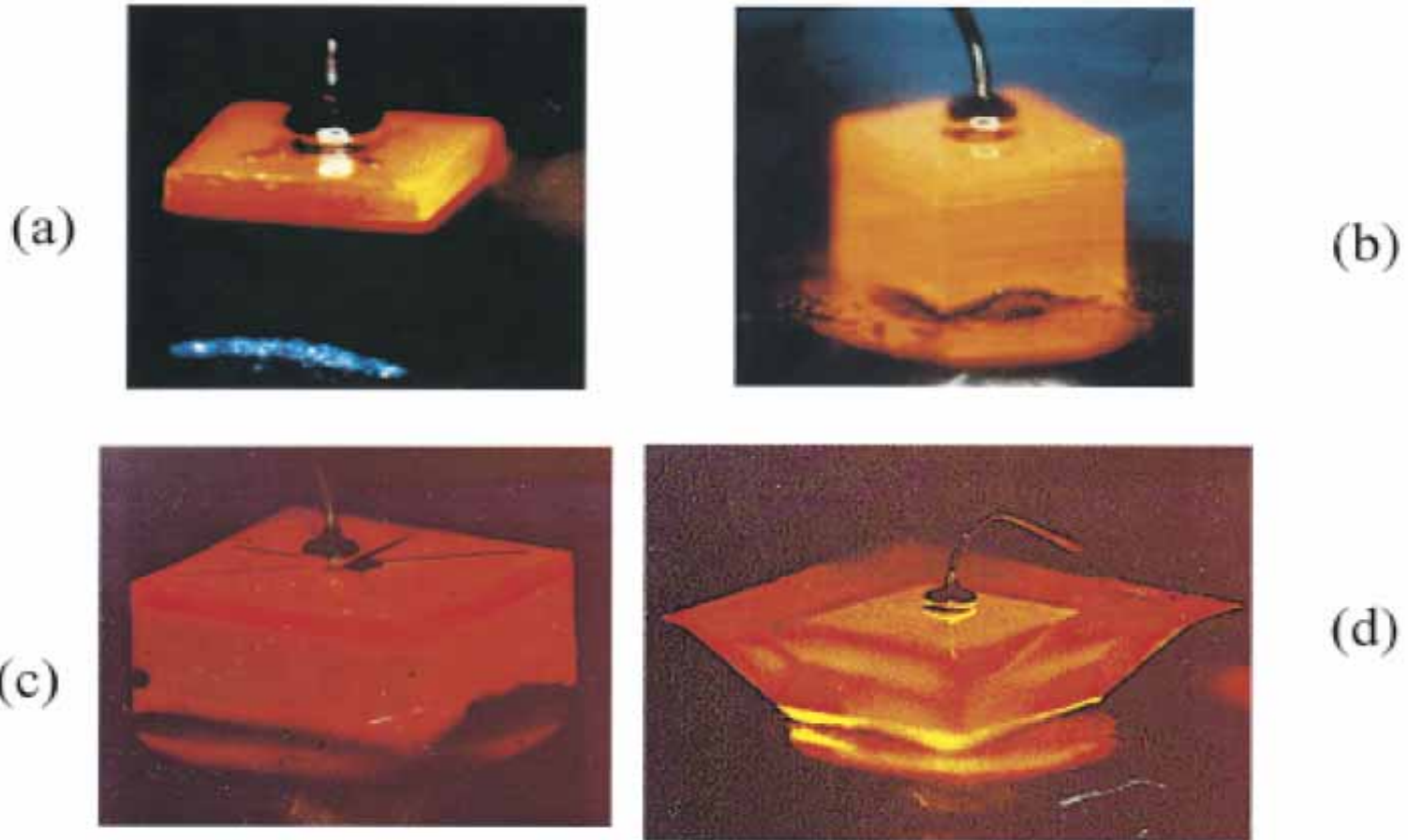


Improved design of LEDs to increase efficiency



The substrates are shown as shaded areas. Early LEDs used light-absorbing substrates (left); later, transparent substrates were developed that permitted light to be emitted in additional directions (center); subsequent shaping of the semiconducting elements (right) has resulted in improved efficiency.

Lumileds AlGaInP LED

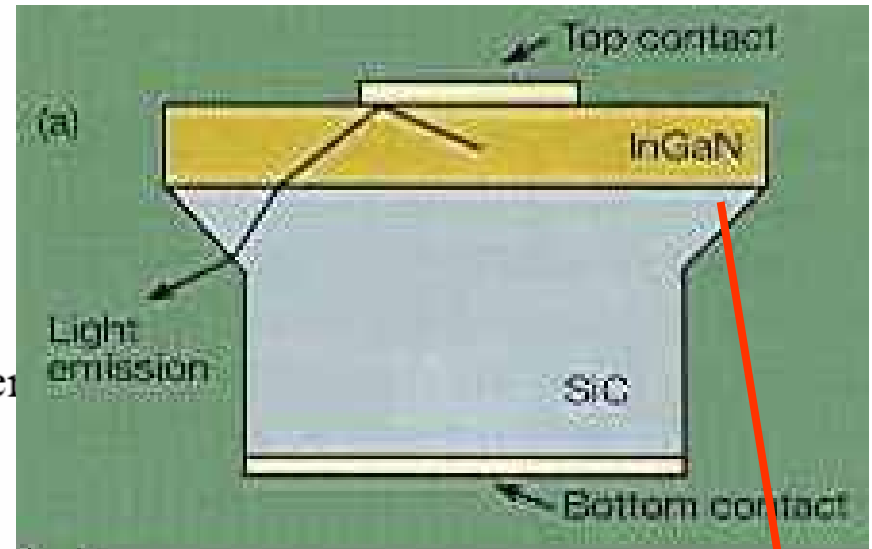
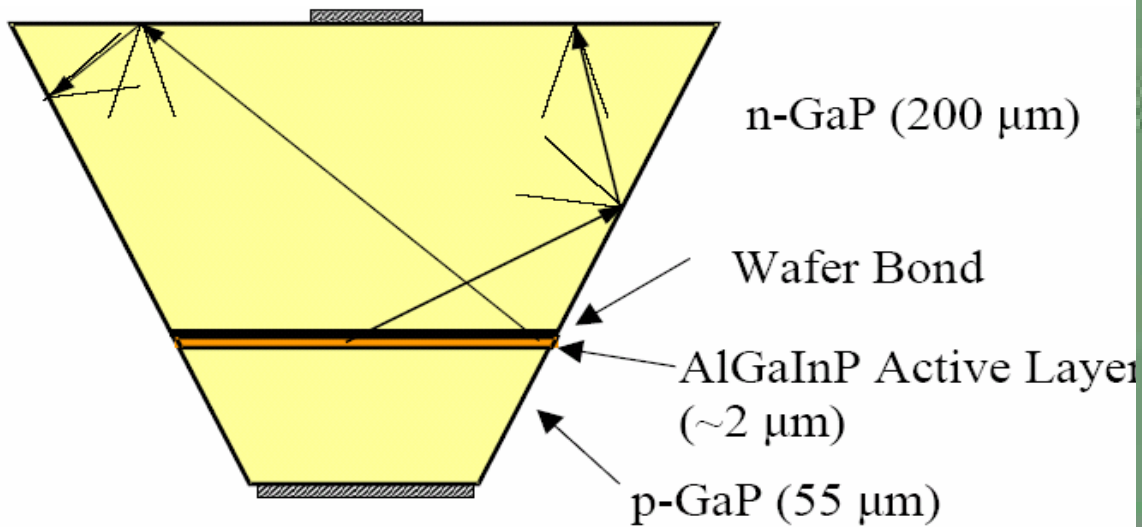


From Lumileds

Fig. 2. Four generations of AlGaInP LEDs: (a) Absorbing substrate (AS) LED. (b) Transparent substrate (TS) LED. (c) High-power LED with $5 \times$ TS flux. (d) Truncation inverted pyramid (TIP) LED with $1.5 \times$ flux of high-power square chip.



Truncated-inverted-pyramid LED

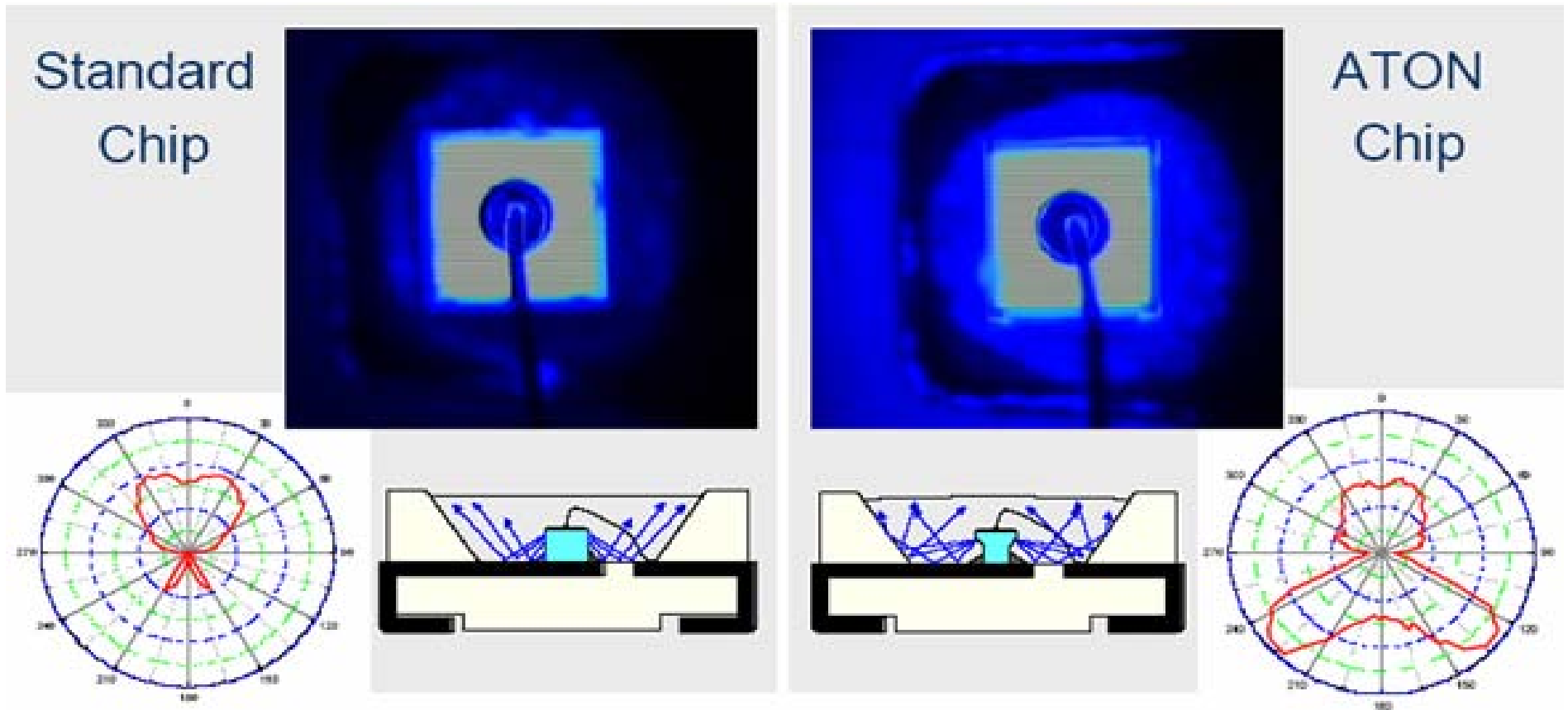


After M. R. Krames *et al.*, *Appl. Phys. Lett.* **75**, 2365, 1999.

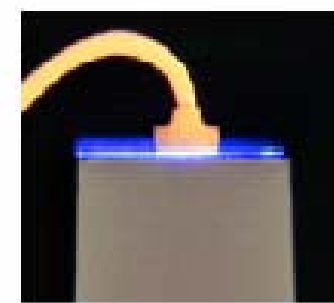
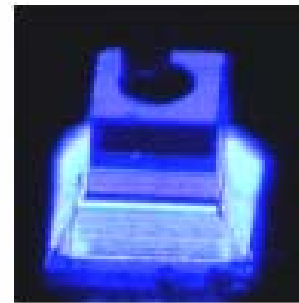
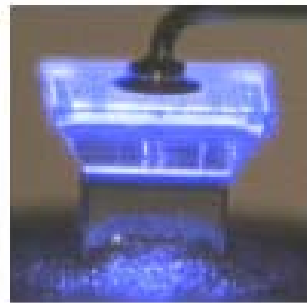
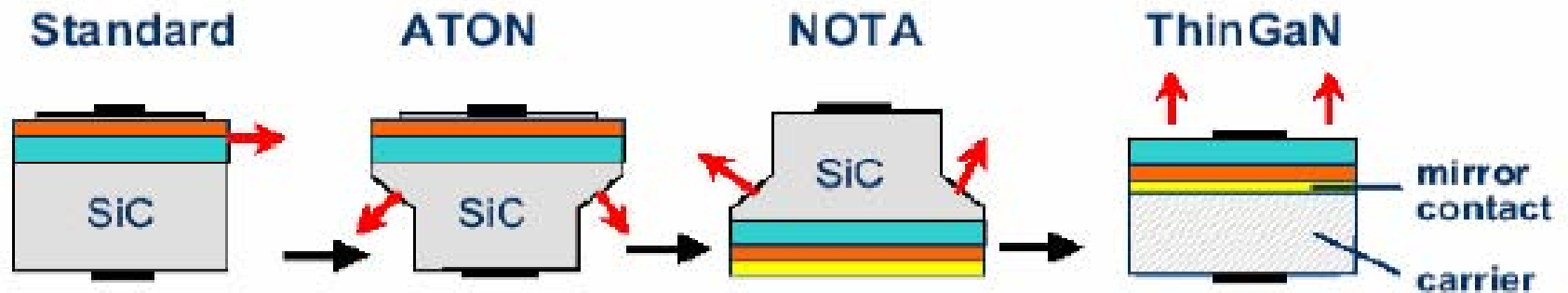
Cree TIP InGaN LED

64°C

Cree Standard and TIP LED的出光表現



Osram's InGaN Chip



$\eta_{\text{extract.}} = 25\%$

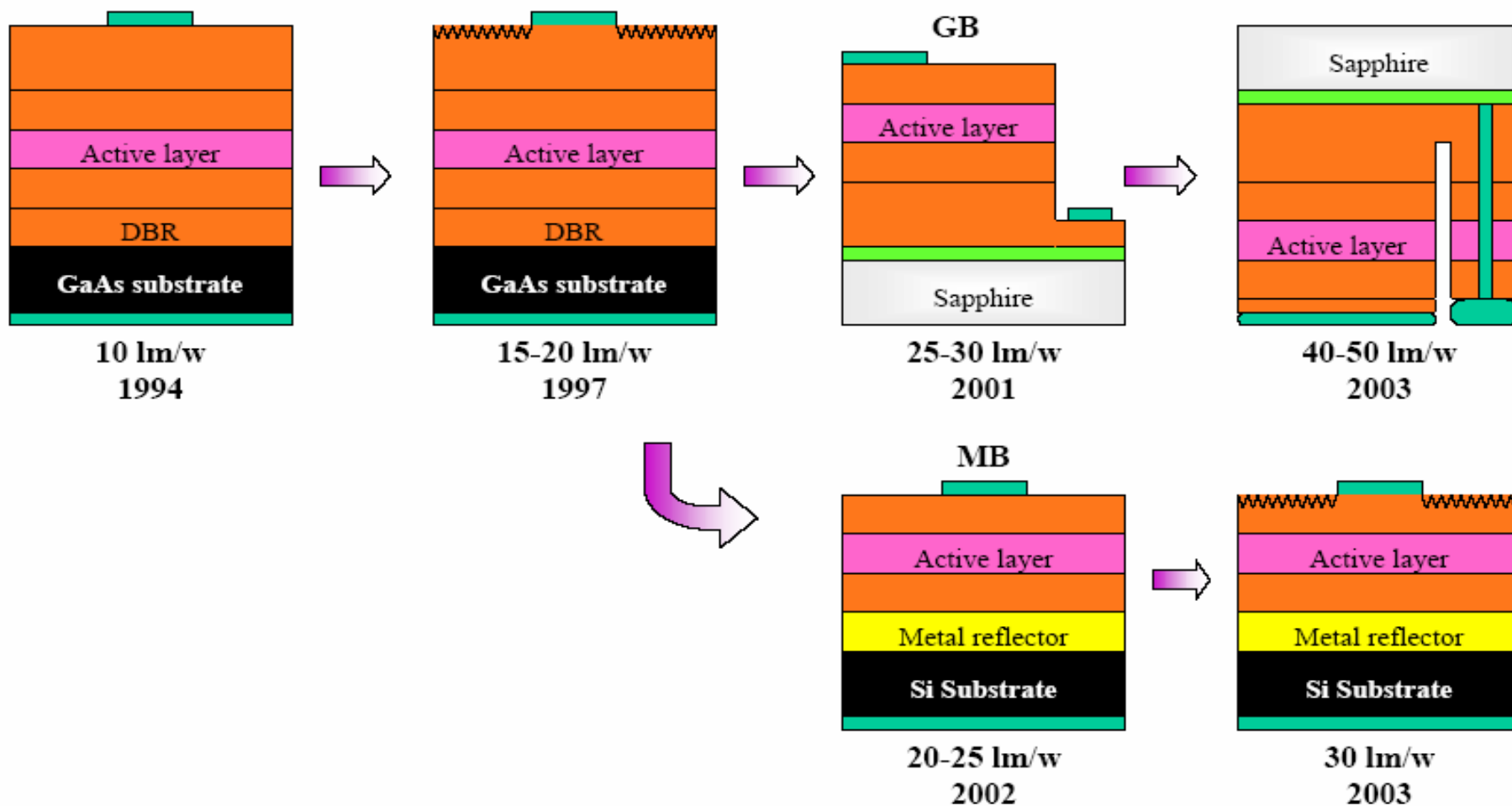
52%

60%

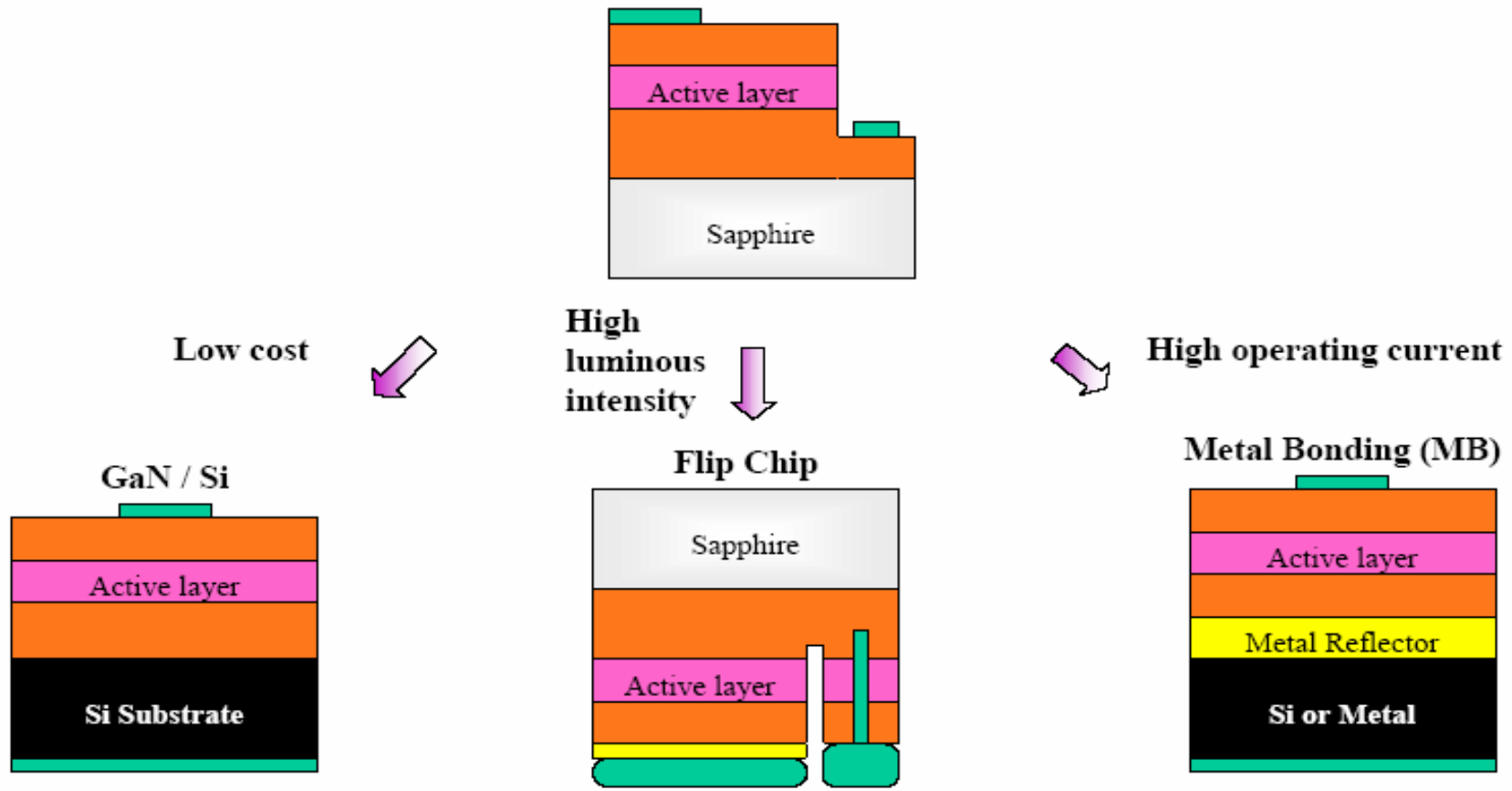
75%



AlGaInP LED

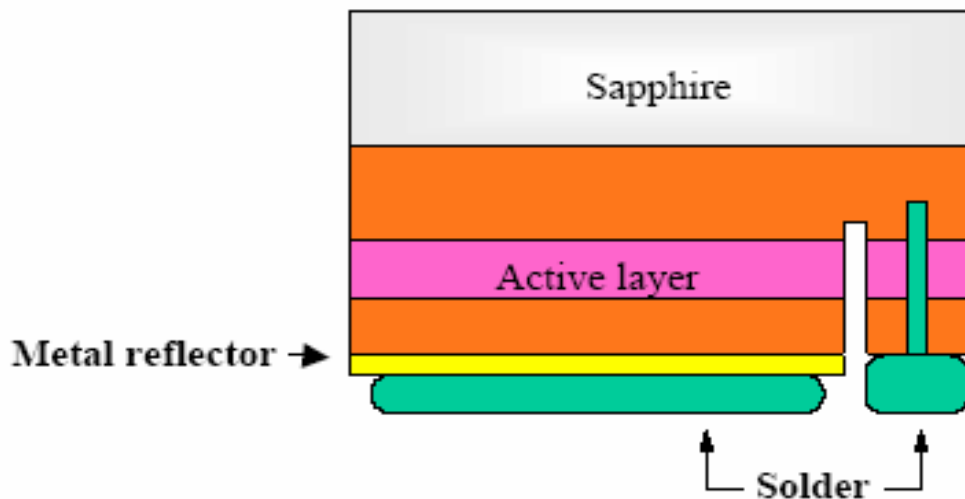


InGaN LED

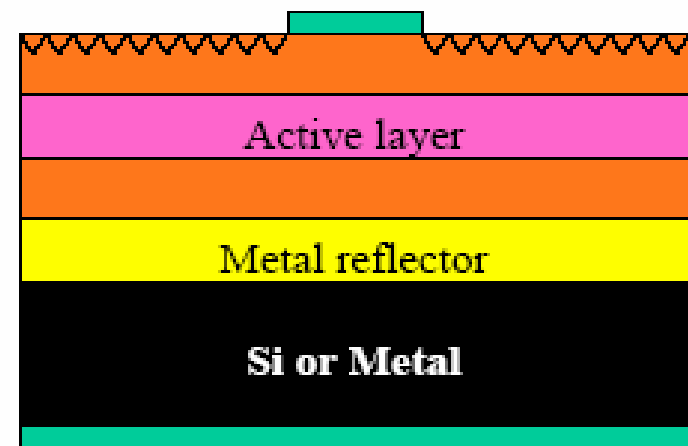


Two Best High Power LED Chip Structures

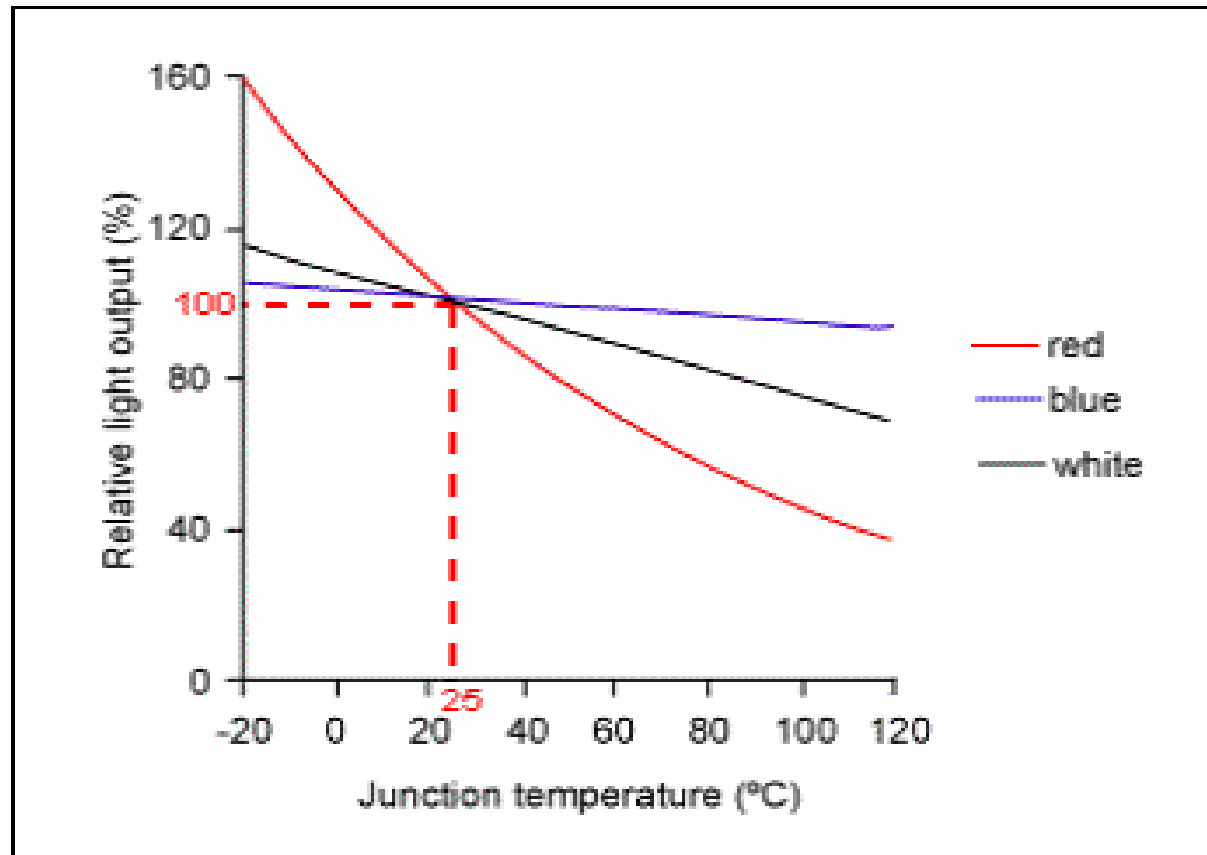
(1) Flip Chip



(2) Metal Bonding



Relative light output of LEDs as a function of the junction temperature

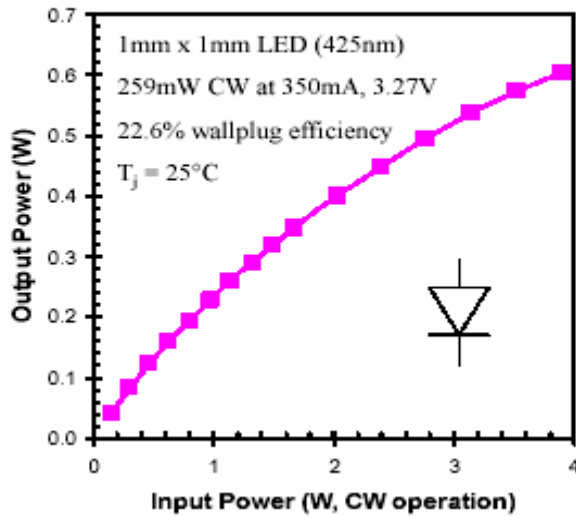


Data based on literature from LumiLeds

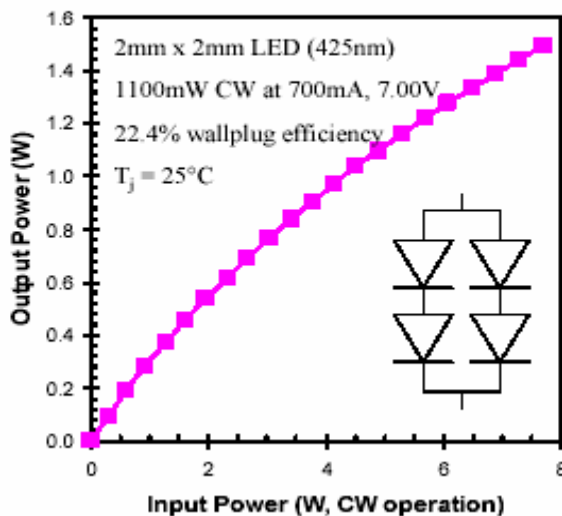
Data are normalized to 100% at a junction temperature of 25°C.

High power LED chip design

1W Luxeon™

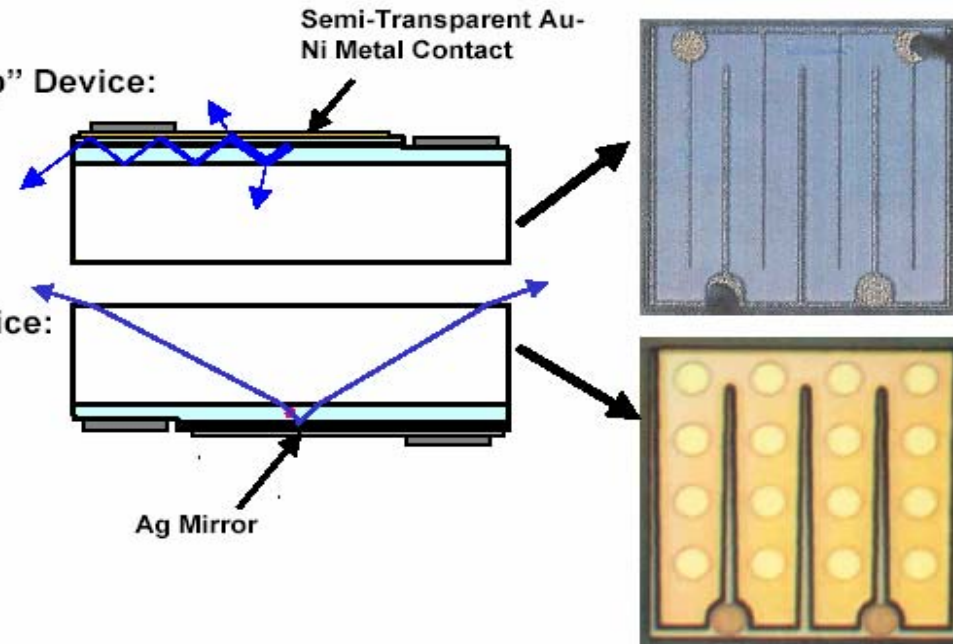


5W Luxeon™



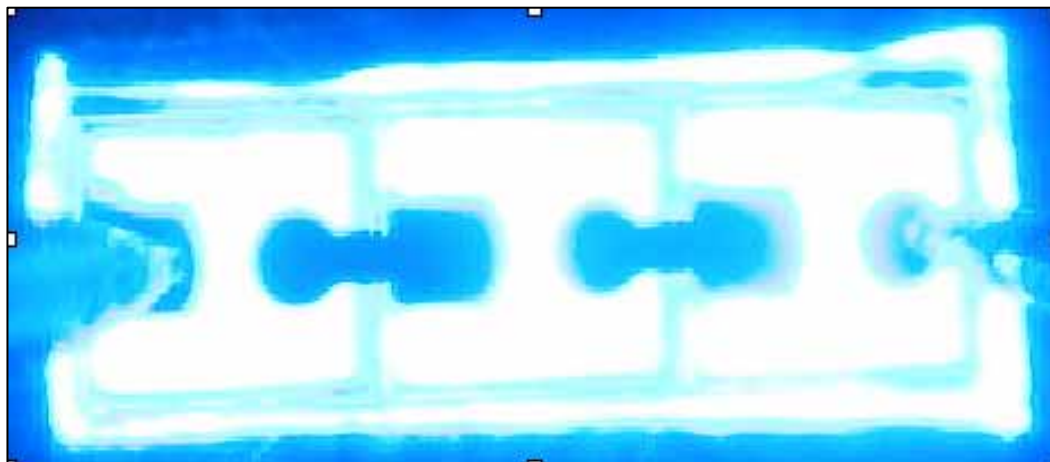
Flip Chip Design for Nitrides

Standard
"Contact-on-top" Device:

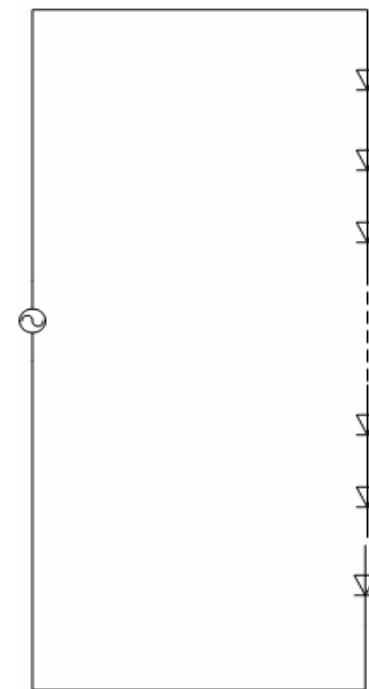


- Flip chip designs have lower thermal resistance and lower absorption and so favorable for integration

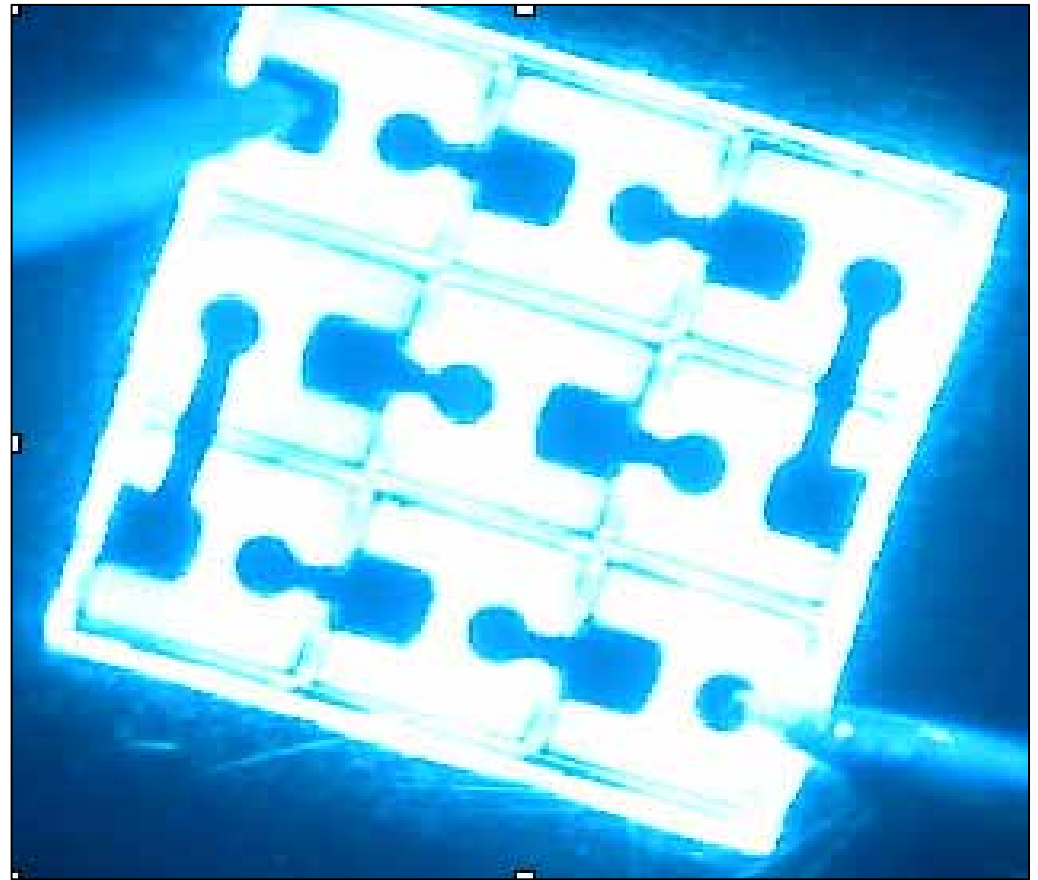
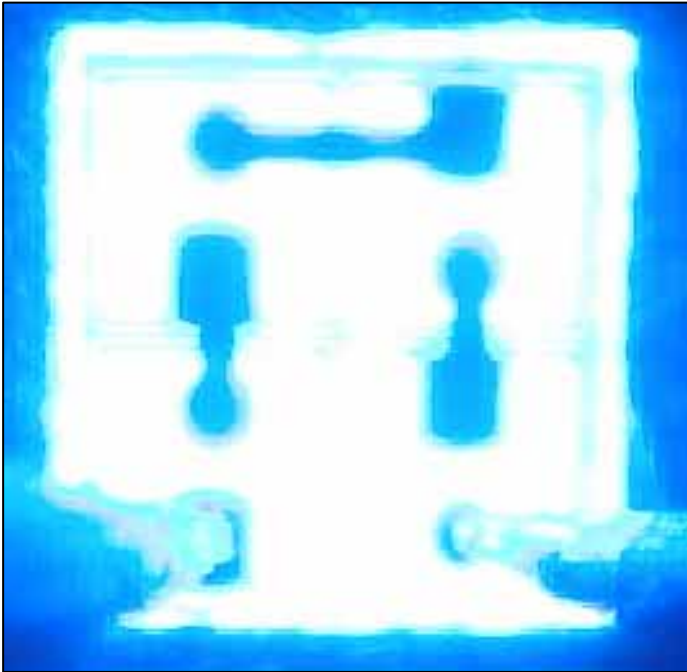
Series chip



$V_f@20mA = 9V$



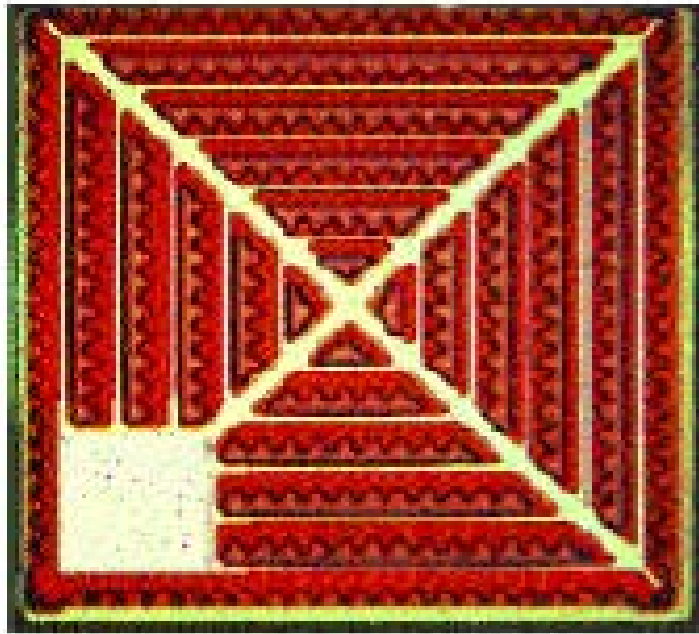
Array LED



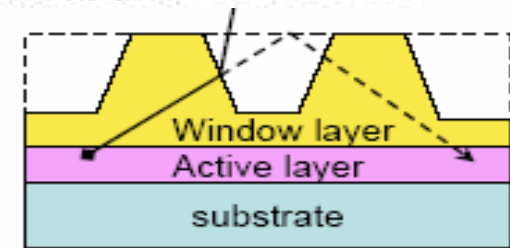
$V_f@20mA=28V$

Increase in the extraction efficiency

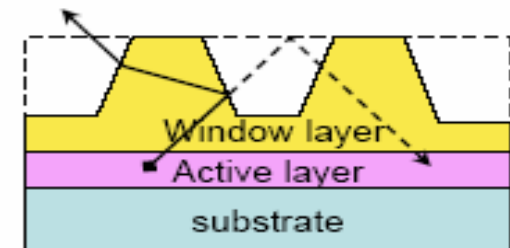
OSRAM AlGaInP Micro-mirror LED



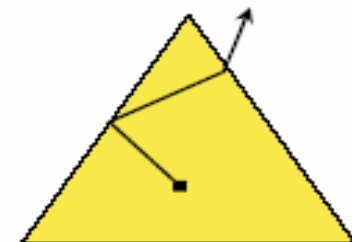
(a) Side view



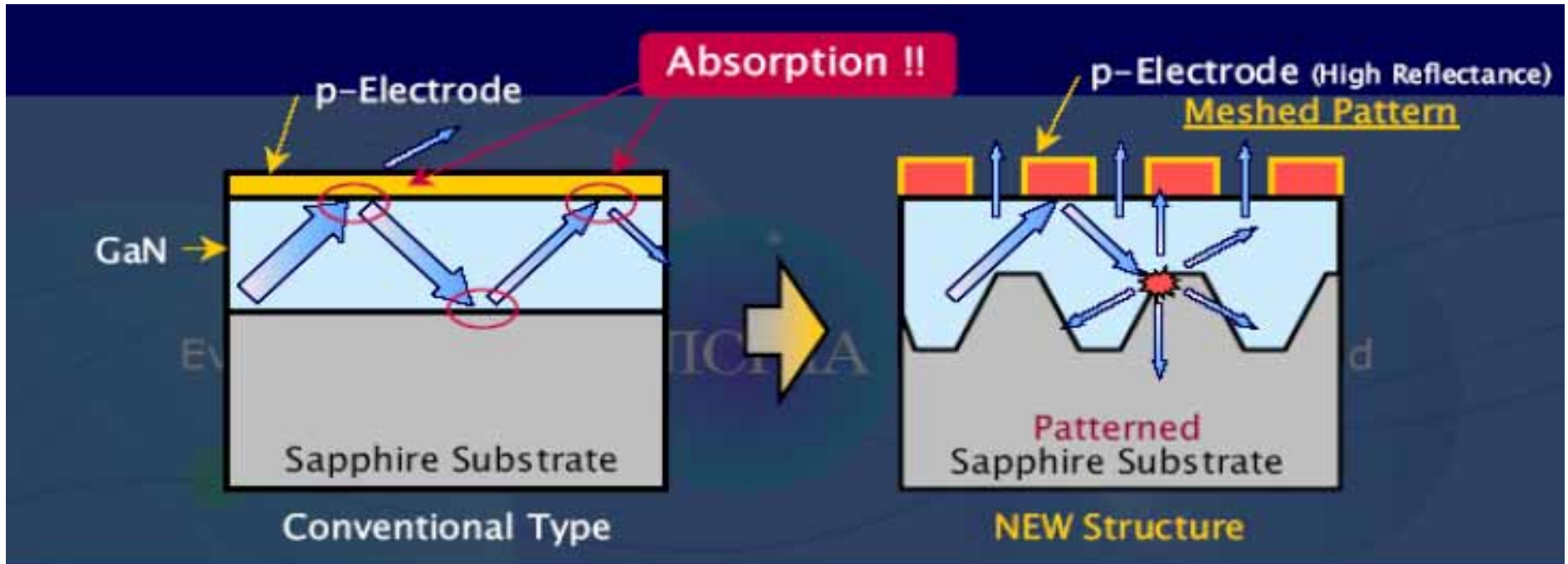
(b) Side view



(c) Top view



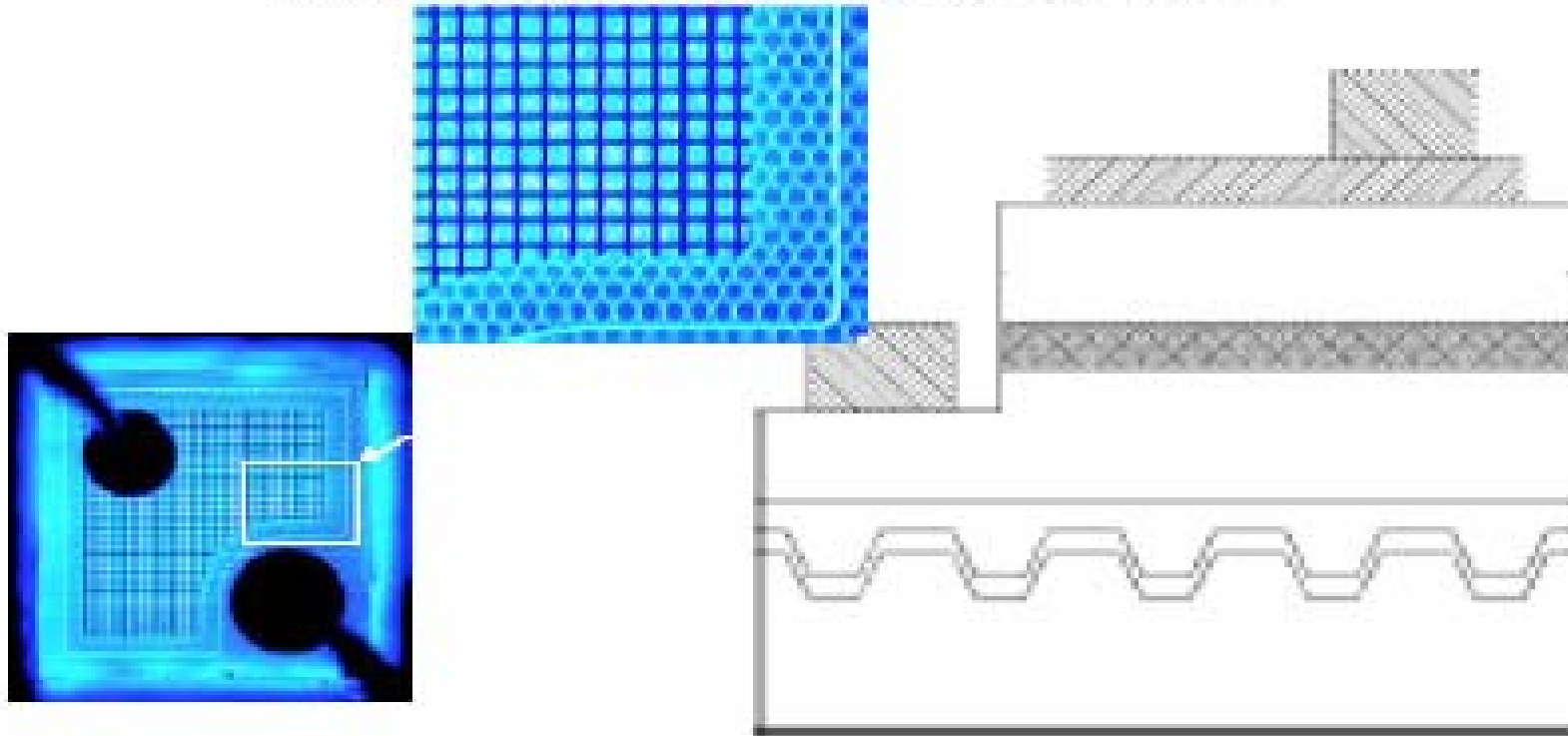
Nichia's high power LED



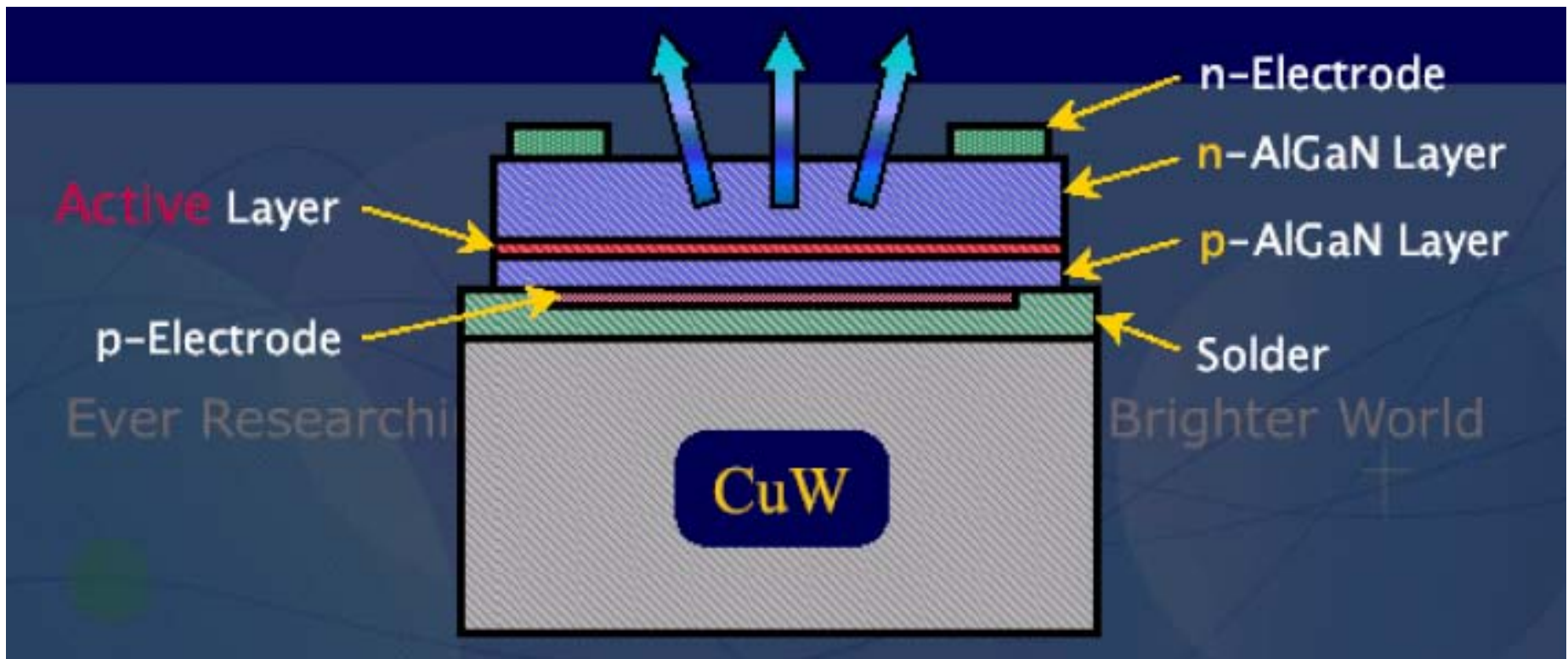
Blue (460 nm) :18.8 mW(external QE:34.9%)
Near UV(400 nm):22 mW(external QE:35.5%)

Increase in the extraction efficiency

Nichia AlInGaN patterned substrate and mesh electrode LED

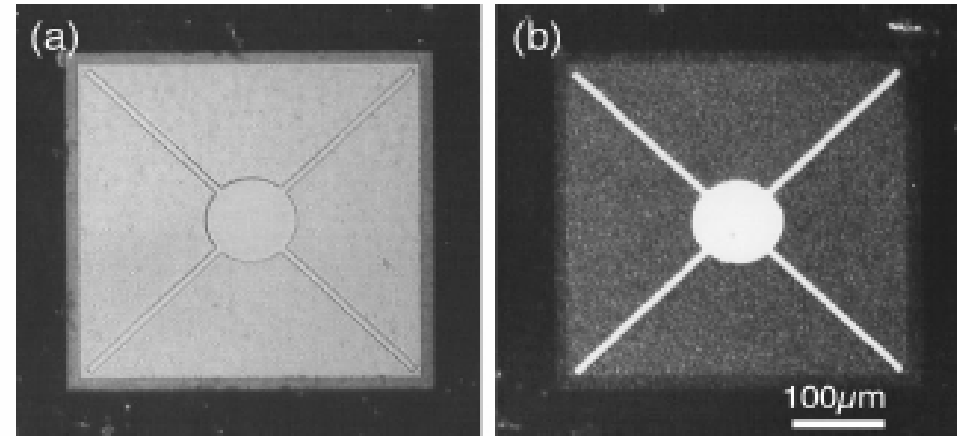
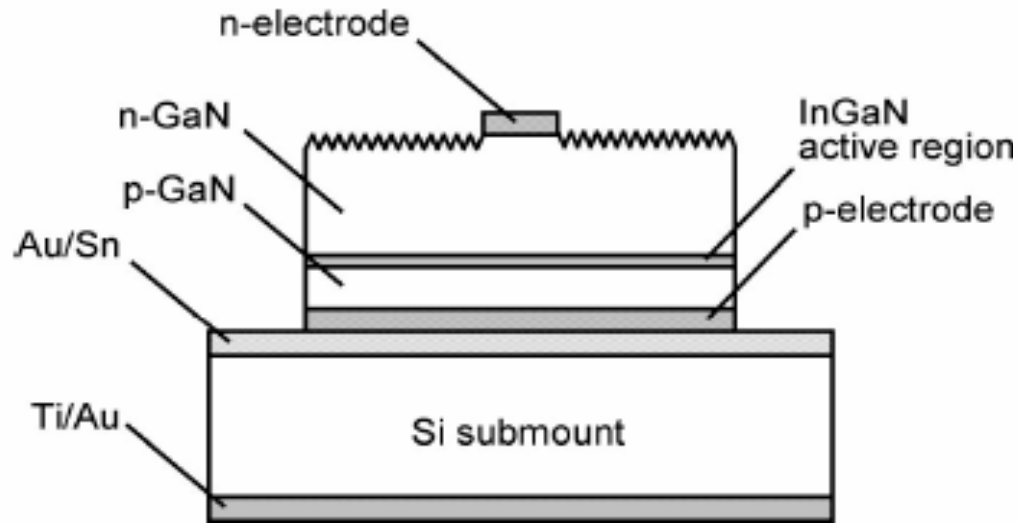


Nichia's high power LED



InGaN Wafer bonding

Increase in the extraction efficiency



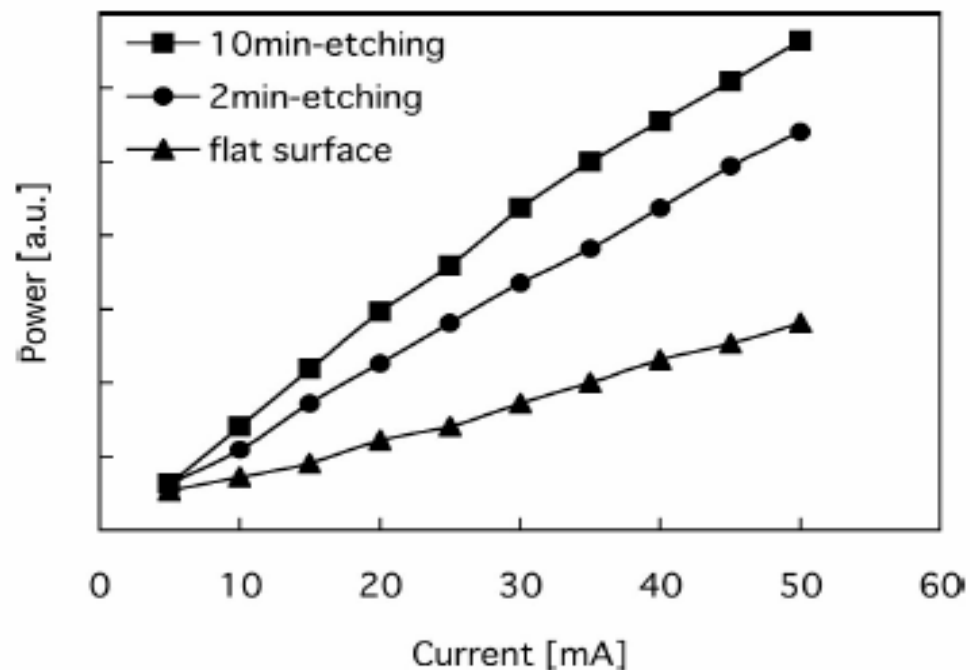
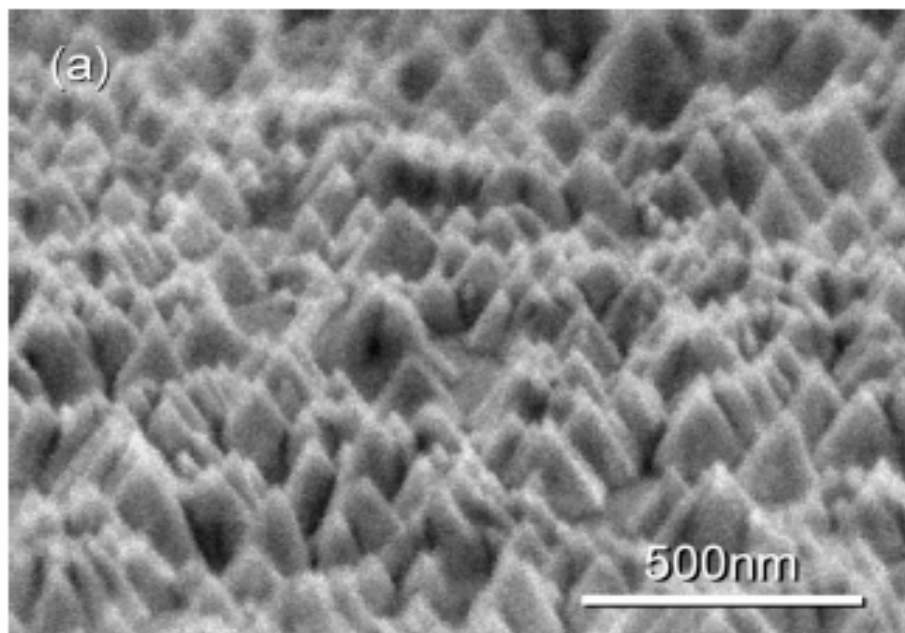
- 基板選擇
- 增加發光效率
- 散熱有效性

- Sapphire去除
- 可靠度
- 生產良率

Appl. Phys. Lett., Vol. 84, No. 6, 9 February 2004

Wafer bonding

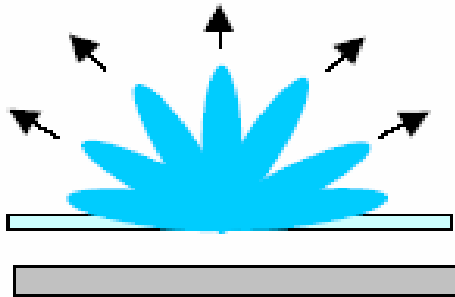
Increase in the extraction efficiency



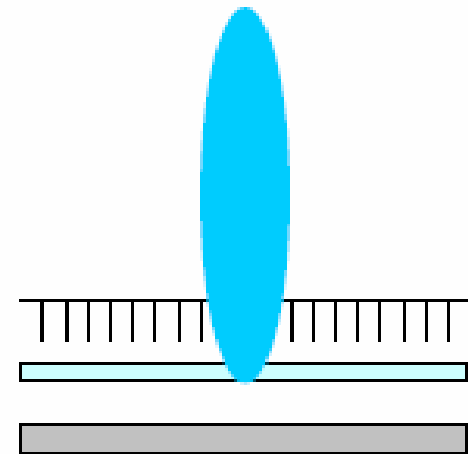
光化學蝕刻

Photonic Crystal LEDs

Flip-Chip LED



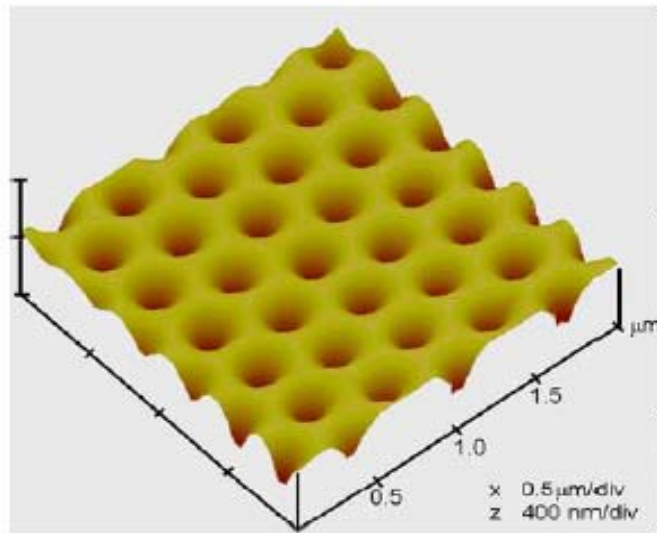
Photonic Crystal LED



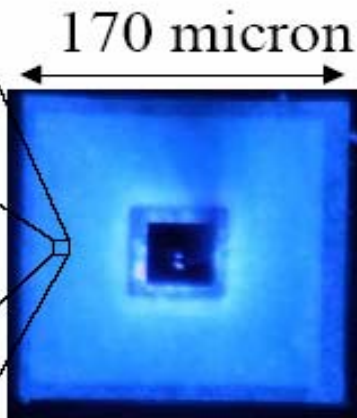
- 光的直向性
- 量產可行性

From Lumileds

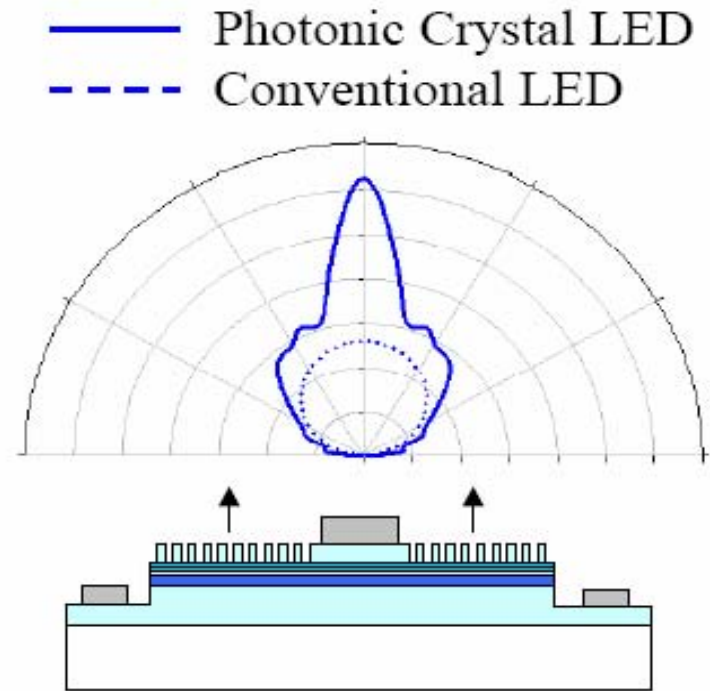
Photonic Crystal LEDs



250 nanometer holes etched into GaN.



Top-view of a Photonic Crystal LED



Light intensity vs. angle. The Photonic Crystal LED's light emission is narrow.

see Wierer et. Al., *Appl. Phys. Lett.*,
Vol. 84 (19), 3885 (2004).

大功率LED製程技術

- **Wafer Bonding Process**
- **Chip Process**
- **Flip chip Process**

LED Wafer Bonding - *mirror substrates*

Metal

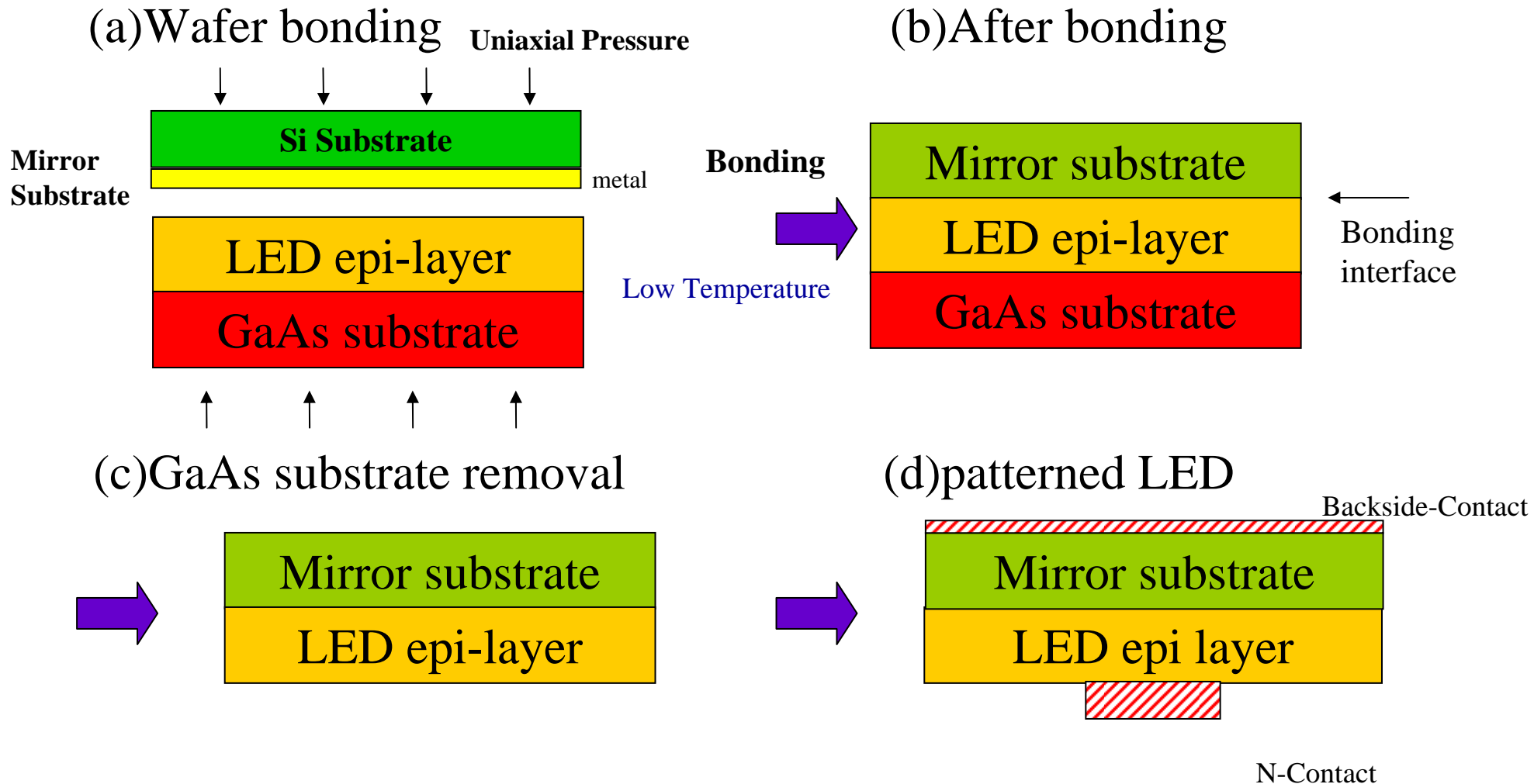
Si Substrate

- Metal with high reflectivity
>90% for red and yellow wavelengths
- Si with excellent thermal conductivity ($\text{Wcm}^{-1}\text{K}^{-1}$)

Si :1.68, GaAs :0.47, GaP : 0.77

From VPEC

VPEC's Wafer Bonding Process



WB-LED – After bonding and removing GaAs sub.



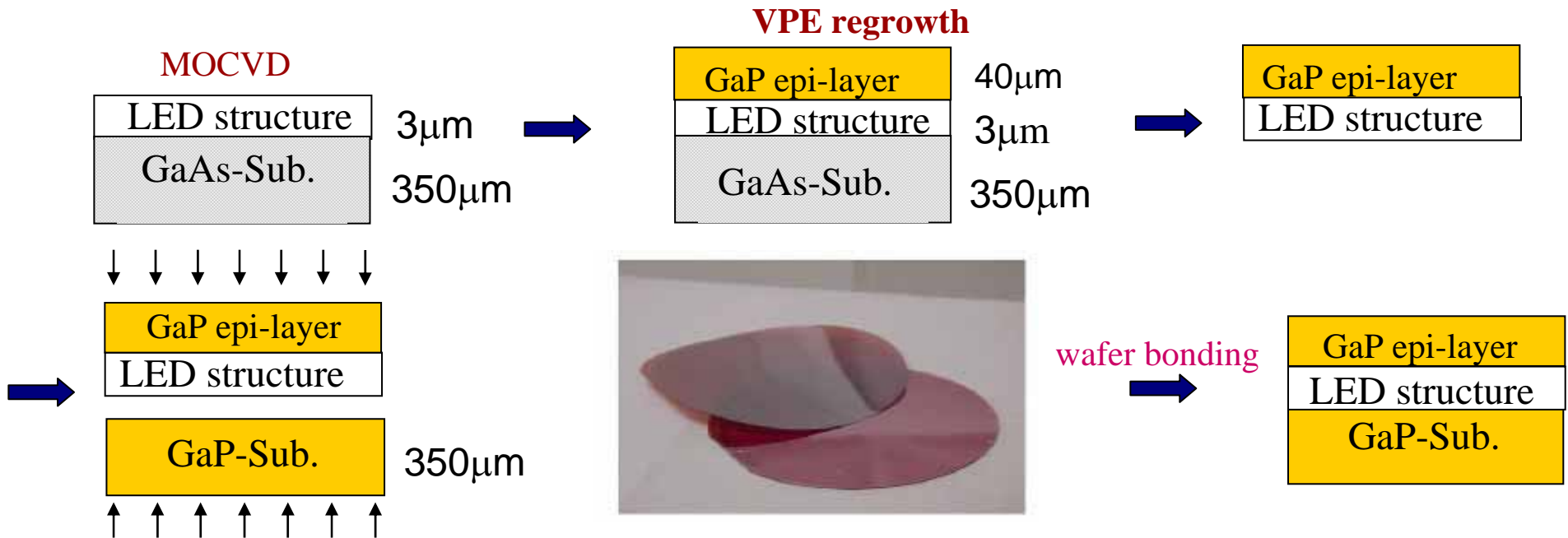
High Bonding Yield

From VPEC

TS-Type LED by Lumileds (HP)

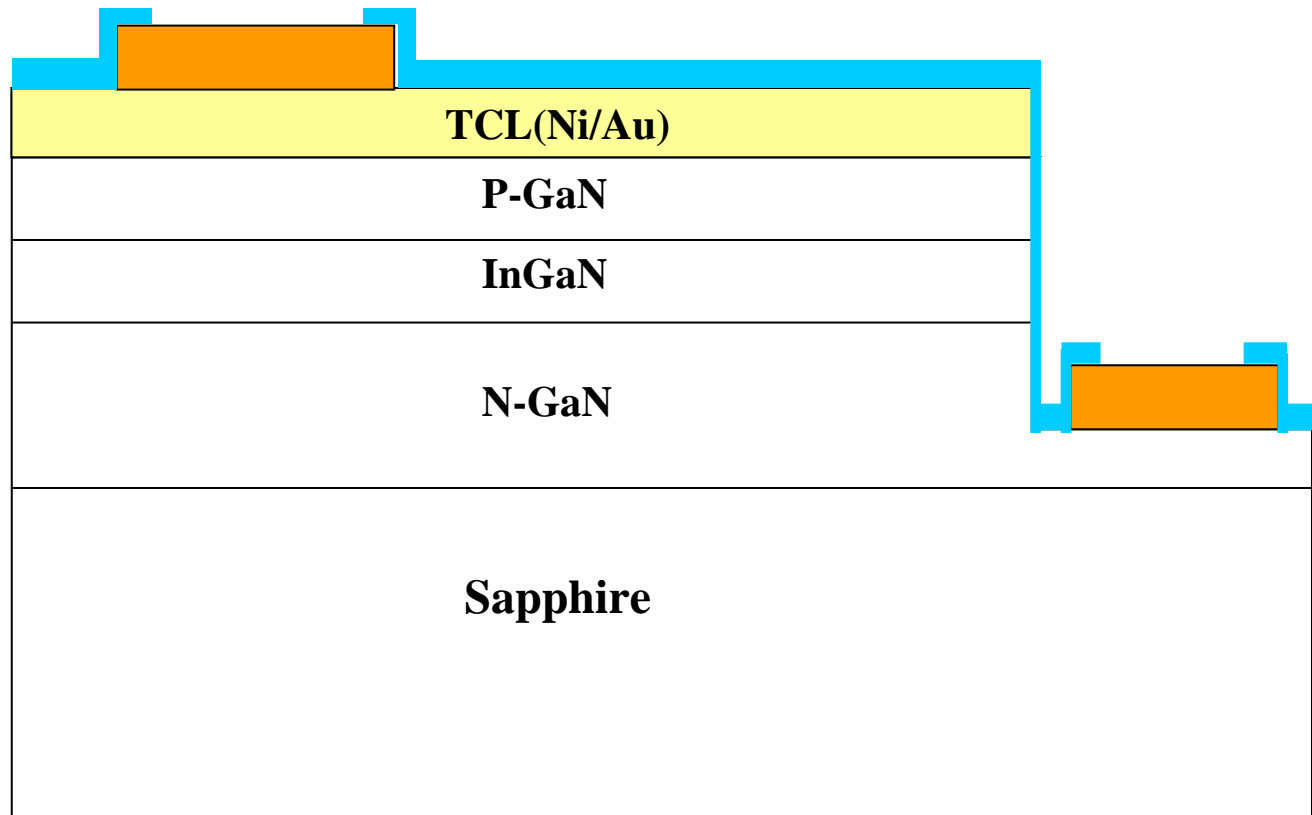
❖ GaP wafer bonding

- Need second growth
- Need to handle thin epi-layer
- High bonding temperature (700°C ~) and long bonding time

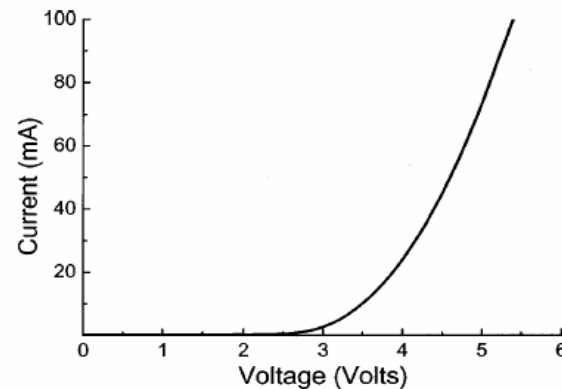
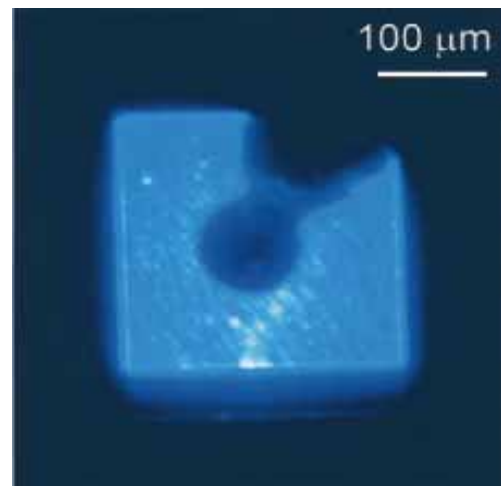
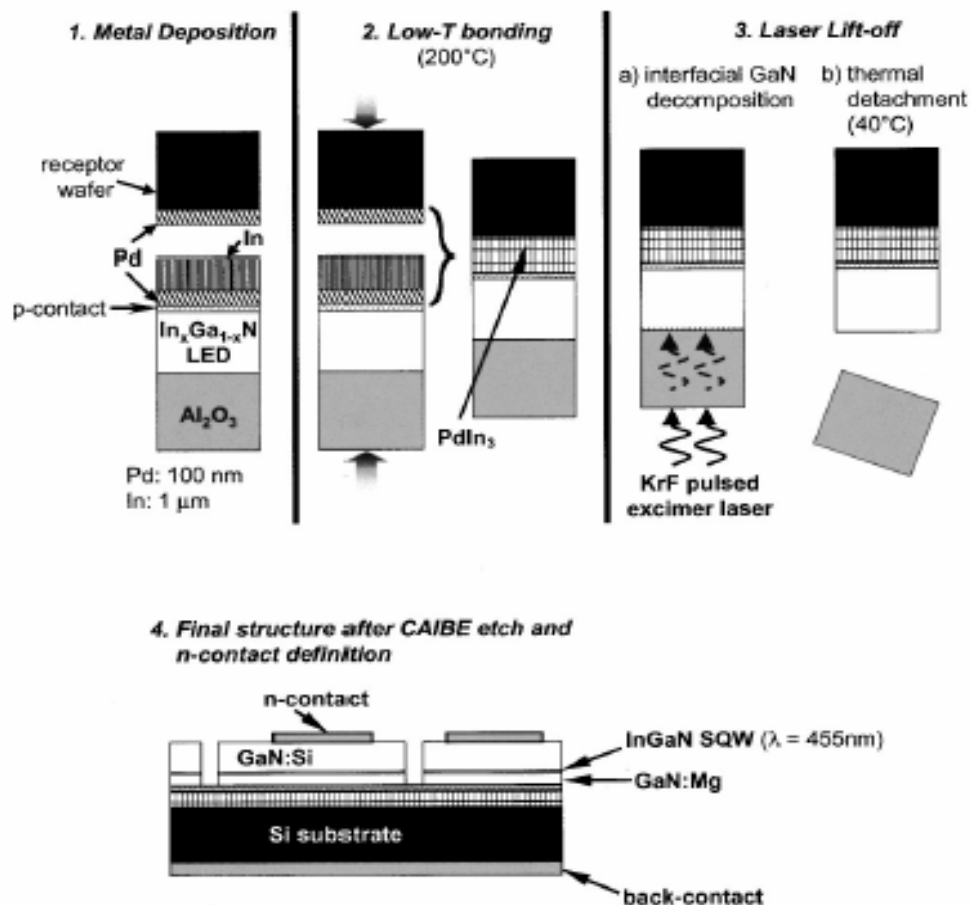


From VPEC

InGaN chip 製程流程



Wafer bonding



電阻較低

FIG. 2. Room-temperature dc I - V characteristics for a typical $250\ \mu\text{m} \times 250\ \mu\text{m}$ InGaN SQW LED on Si.



After bonding and removing Sapphire substrate

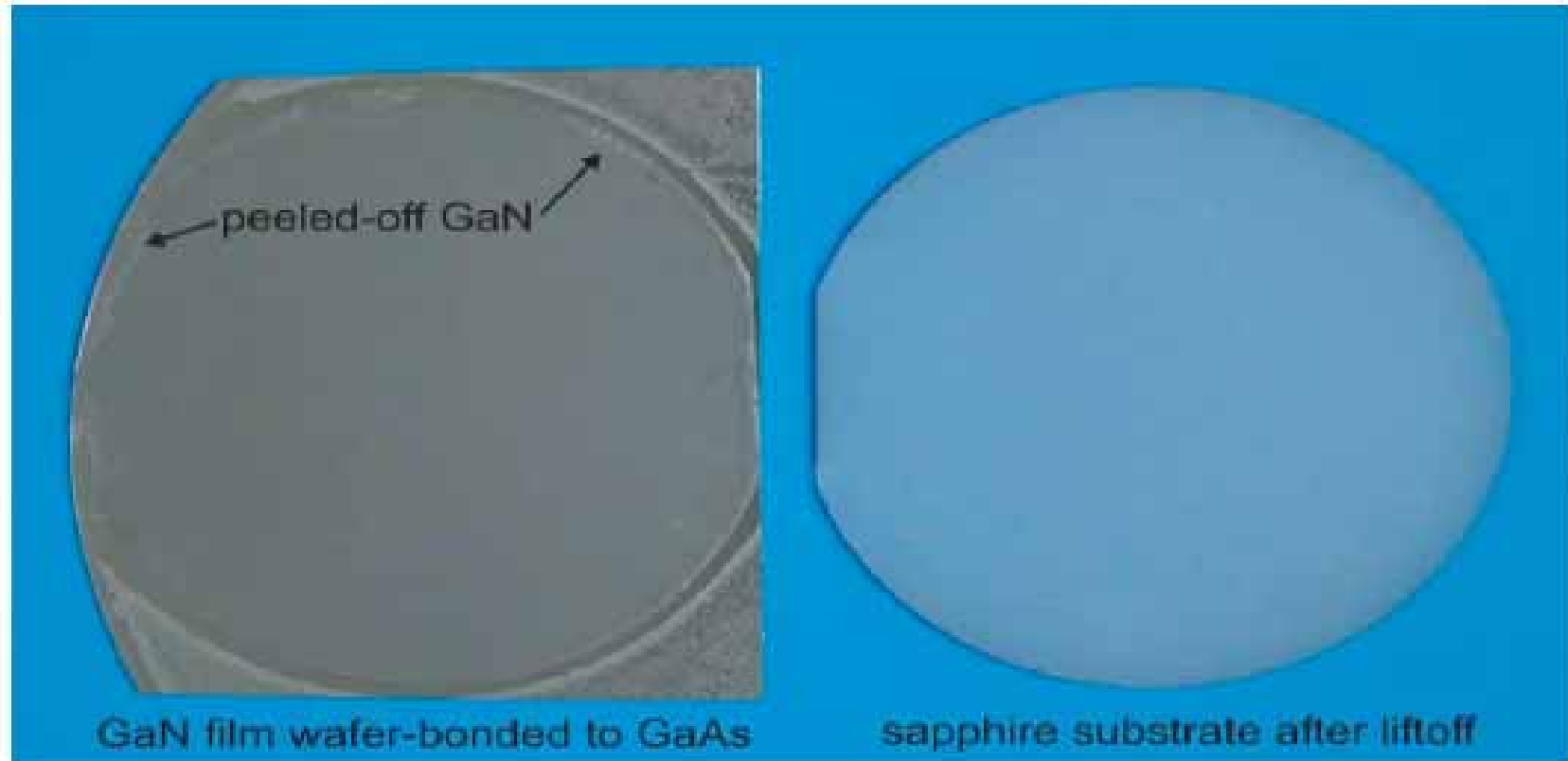
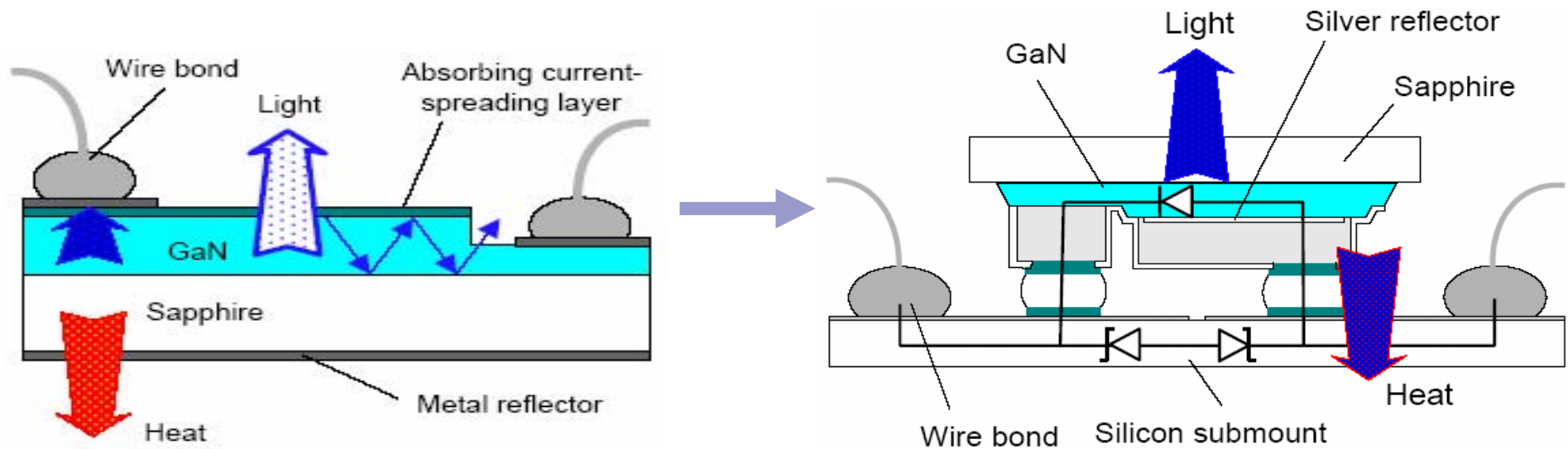


Fig. 13 (online colour at: www.interscience.wiley.com) Delaminated 3 μm thick 2" GaN film (not structured) wafer-bonded onto GaAs (left) and the corresponding GaN-free sapphire substrate (right). The transferred GaN film is essentially defect free, except for some peeled-off areas at the wafer rim.

Diagram of Flip chip



From Dr. R. Scott Kern Lumileds Lighting

Thermal conductivities of the materials

GaAs	44-58
$\text{Al}_{0.5}\text{Ga}_{0.5}\text{As}$	11
$(\text{Al}_{0.5}\text{Ga}_{0.5})_{0.5}\text{In}_{0.5}\text{P}$	6
$\text{Ga}_{0.5}\text{In}_{0.5}\text{P}$	5
GaP	75-79
Sapphire	35-40
GaN	a.130 b.170-180
Si	125-150
SiC	283
Copper	398
Silver	427
Gold	315
Aluminum	237
Au-Sn (80-20)	57.3
In	81.8-86
Aluminum Nitride	a.170-200 b.285
SiO_2	1.2
Al_2O_3	20-27



Models for Flip chip bonding

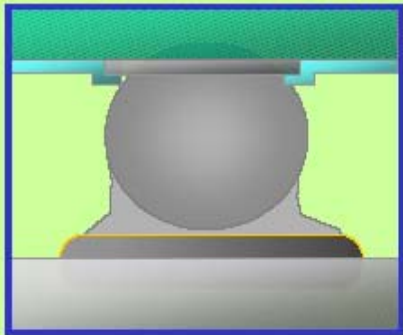
LED Flip chip考量:

- 良率(對位精度)
- 晶片 1mm 以下
- 腳數少
- 溫度
- 污染
- 速度

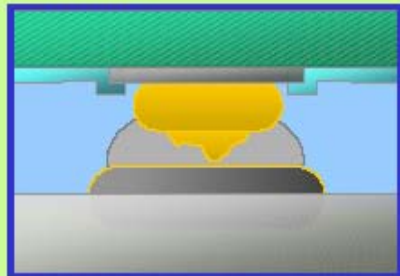


Ultrasonic Flip chip

Connections by metal bonding



C4 (solder-solder)

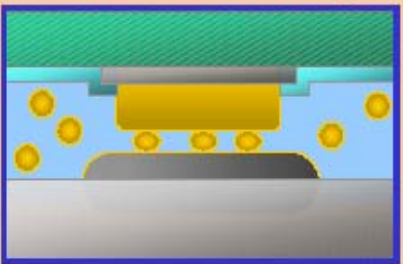


ESC (gold-solder)



Ultrasonic FC (gold-gold)

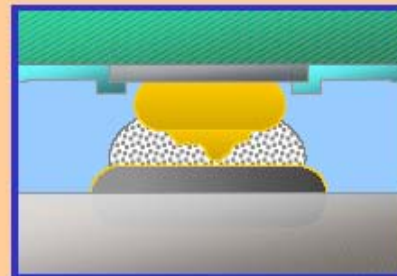
Connections by contact



ACF/ACP

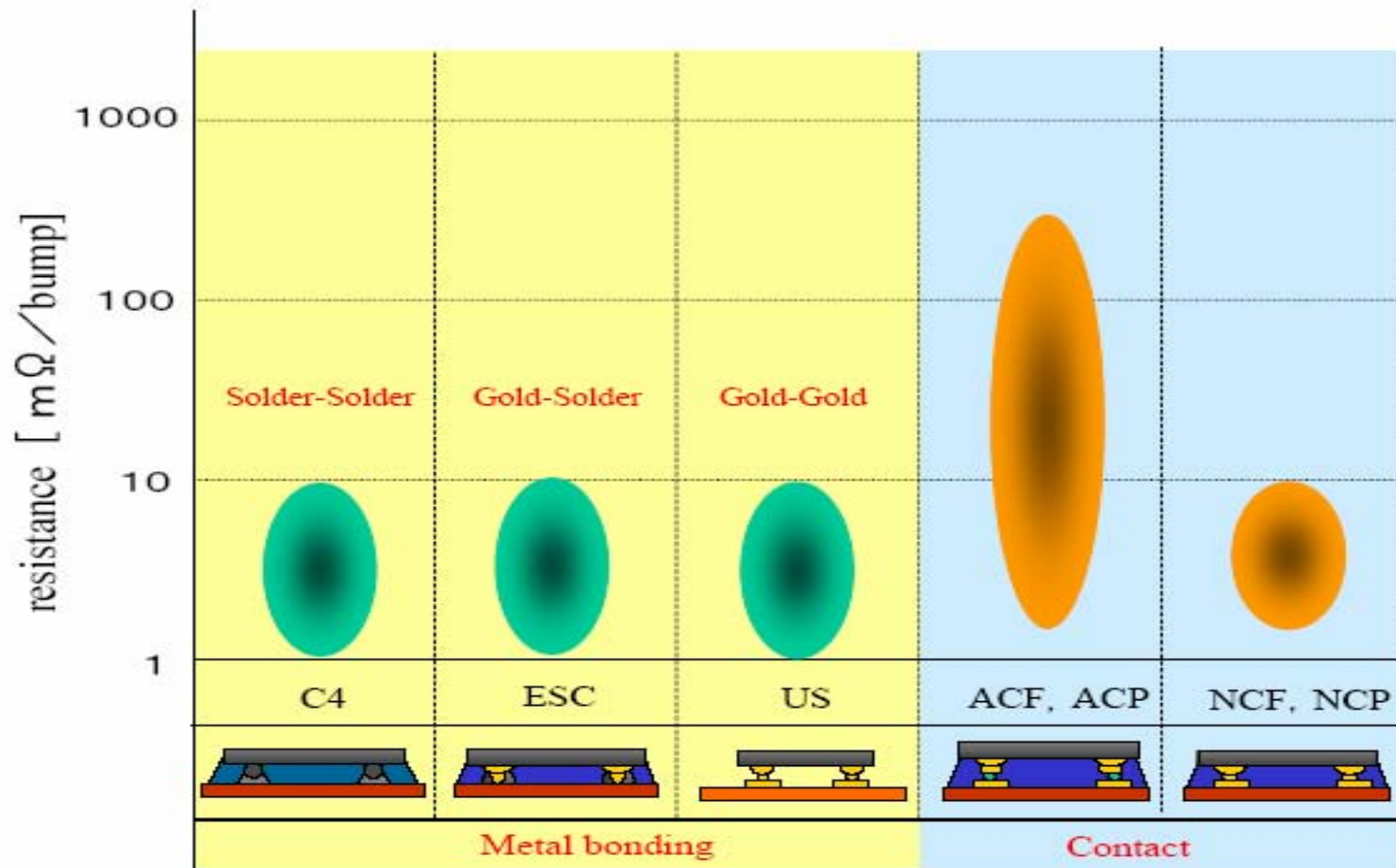


NCP

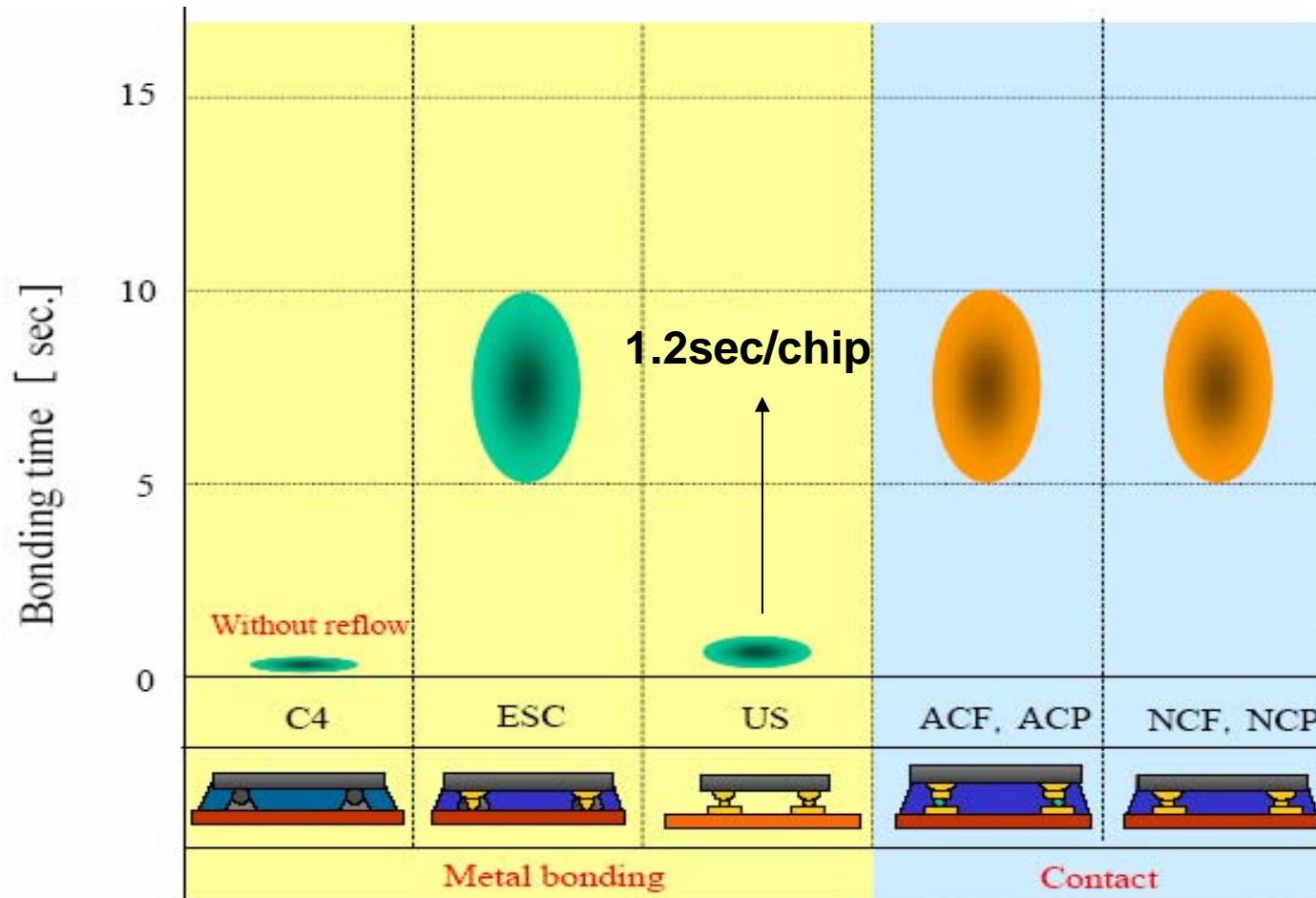


SBB

Resistance of flip-chip bonding

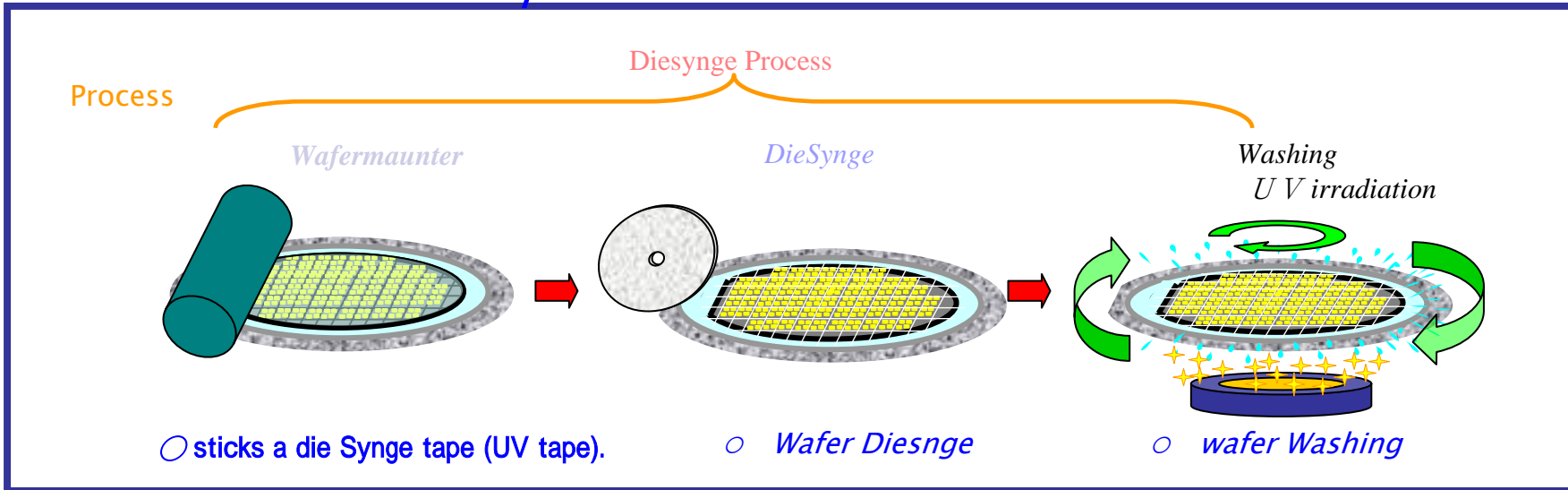


Process time of flip-chip bonding

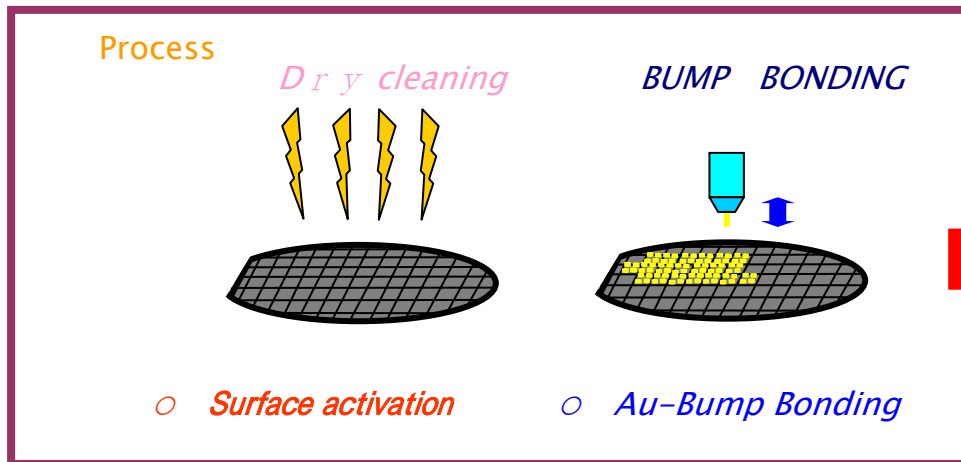


Line composition of LED

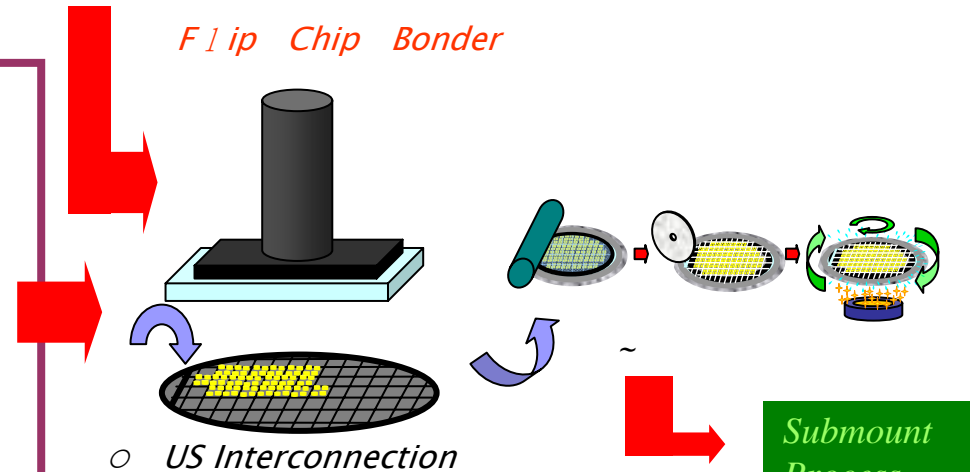
Chip Side



Substrate Side

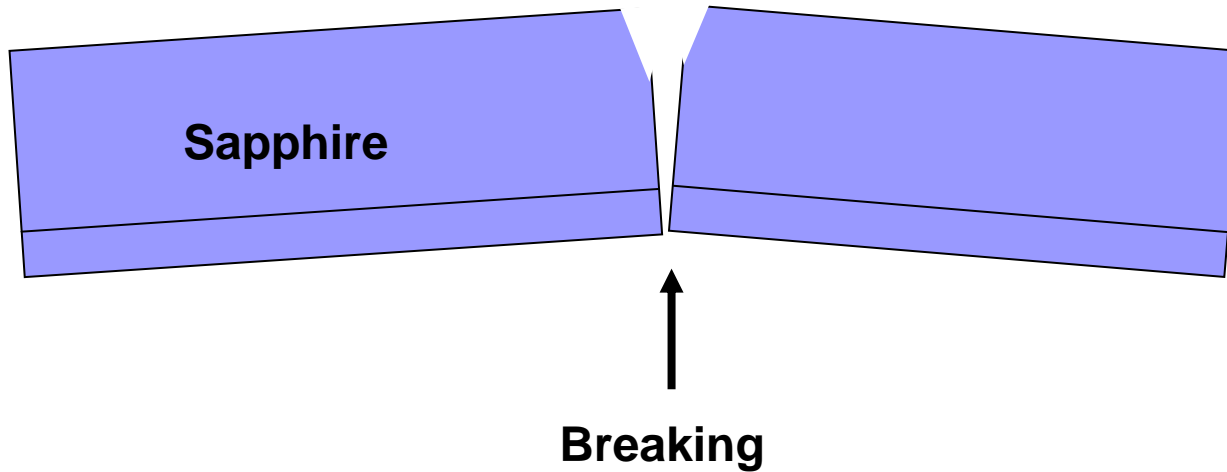
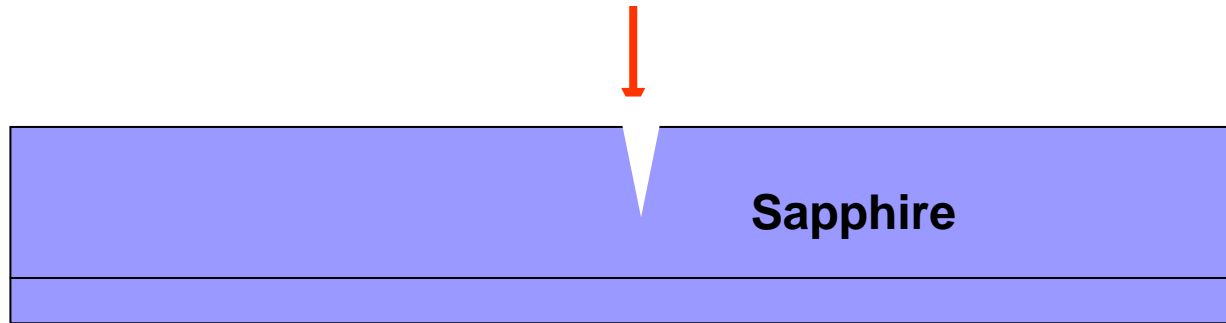


Flip Chip Bonder

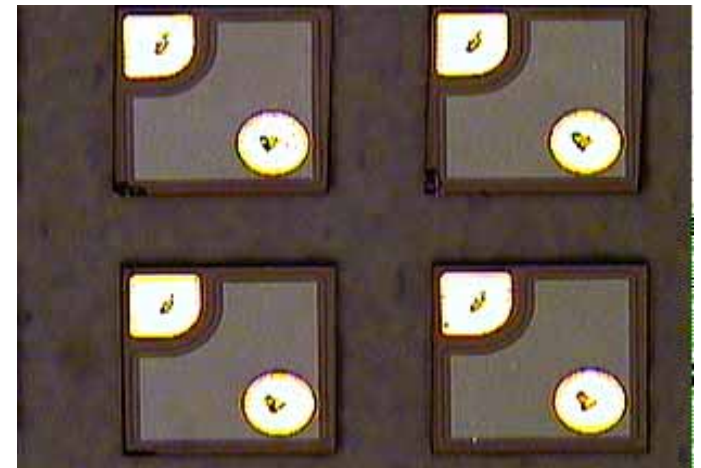
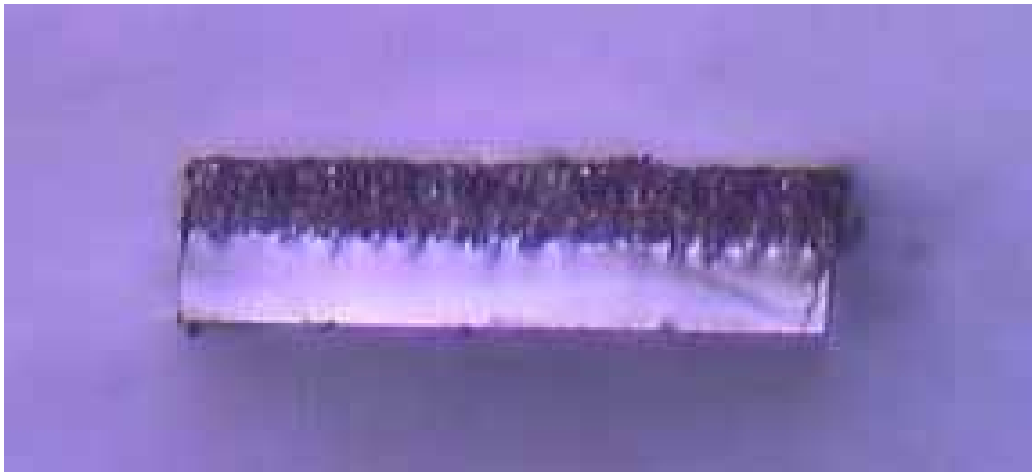
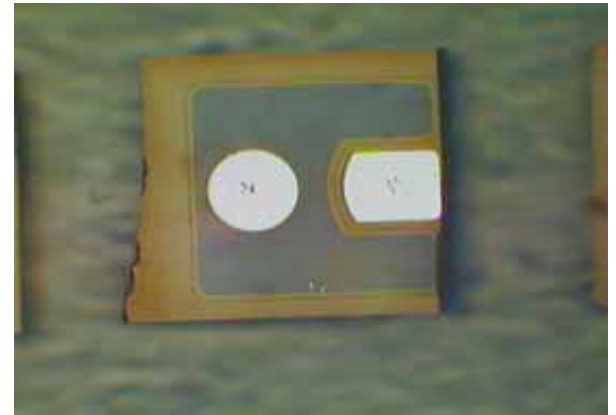
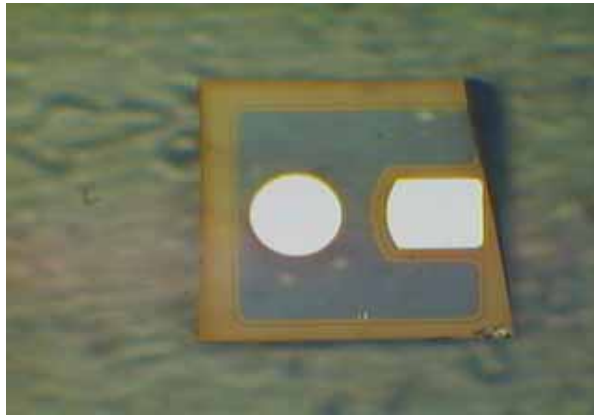
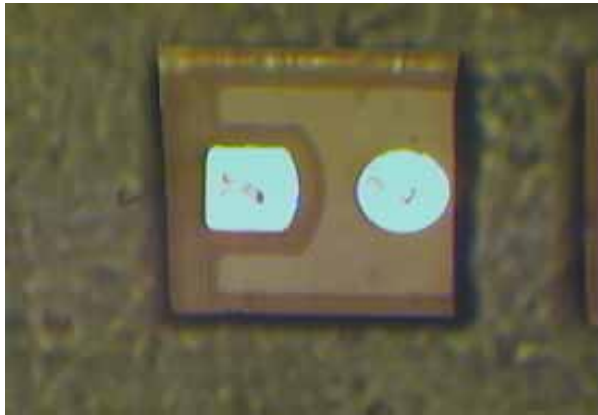


Scriber

Laser or Diamond



鑽石切割與雷射切割



共晶接合

專利 Lumileds-1

見圖6b

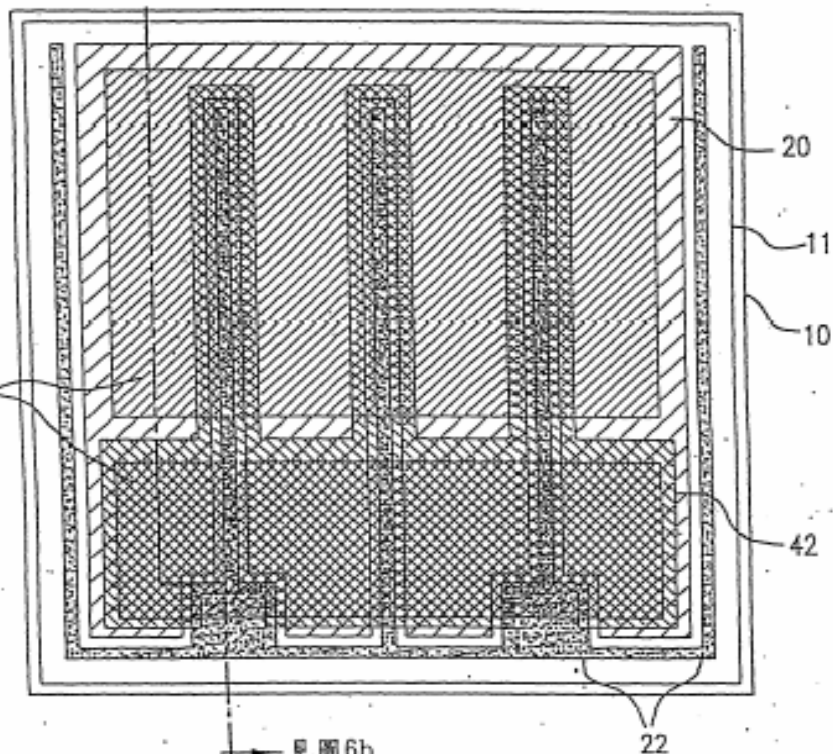


圖 6(a)

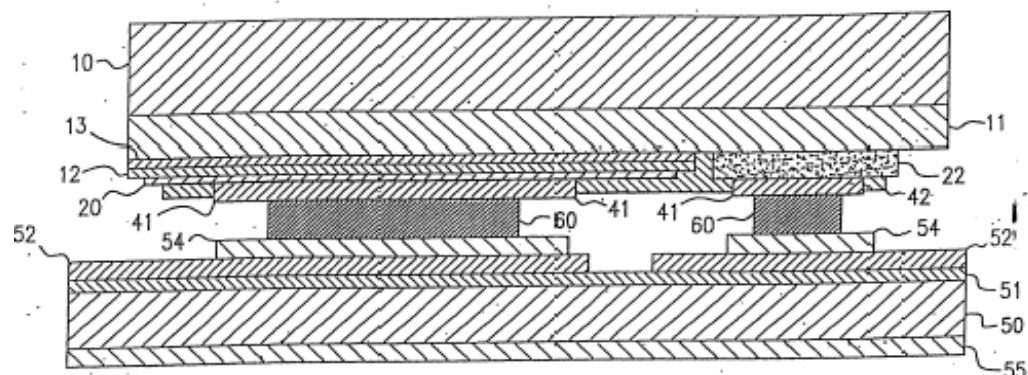


圖 6(b)

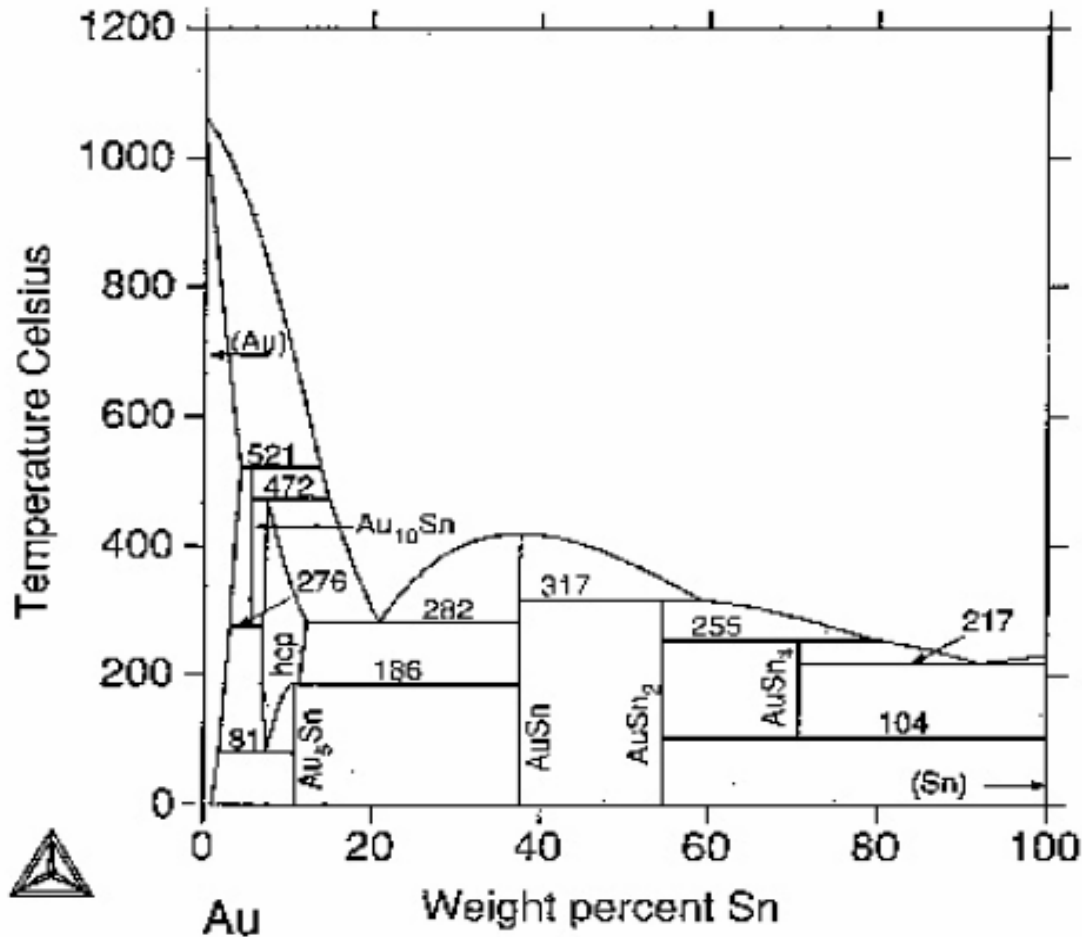
大功率使用時的可靠度?

接合精度

溫度對LED影響



Au-Sn phase diagram



- Eutectic Point
 $AuSn(80/20):282^{\circ}C$

- Eutectic Point
 $AuSn(10/90):217^{\circ}C$



超音波接合

專利 Lumileds-2

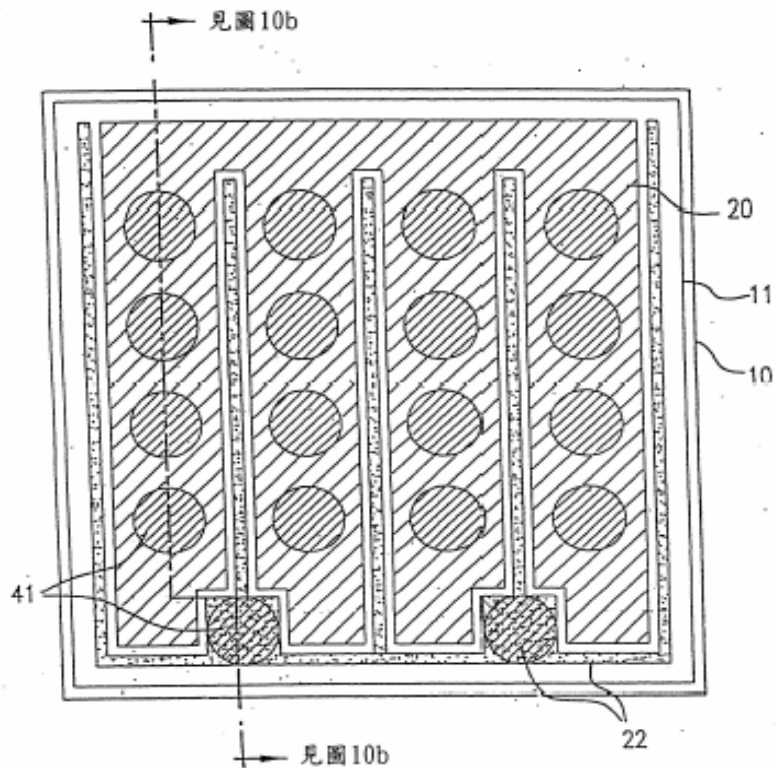


圖 10(a)

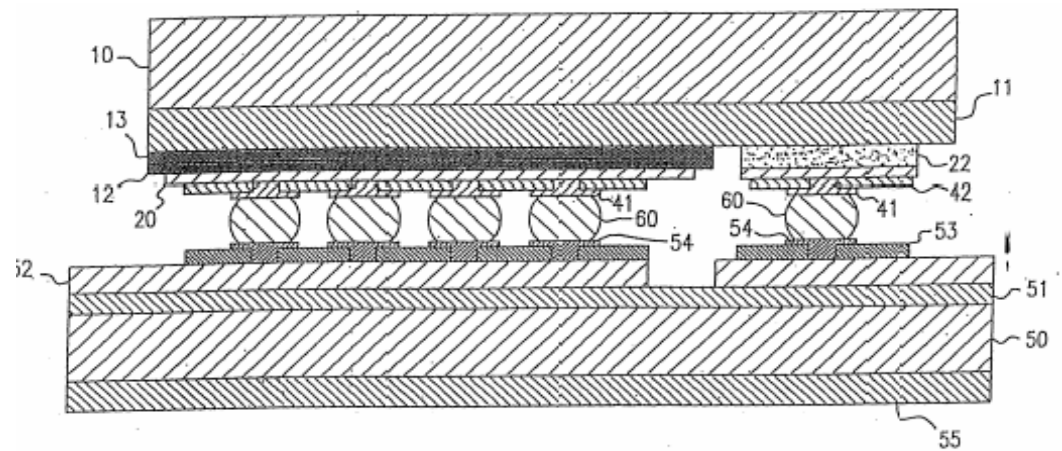


圖 10(b)

構裝時的精準度?

誤差 < 10um

專利 Lumileds-3

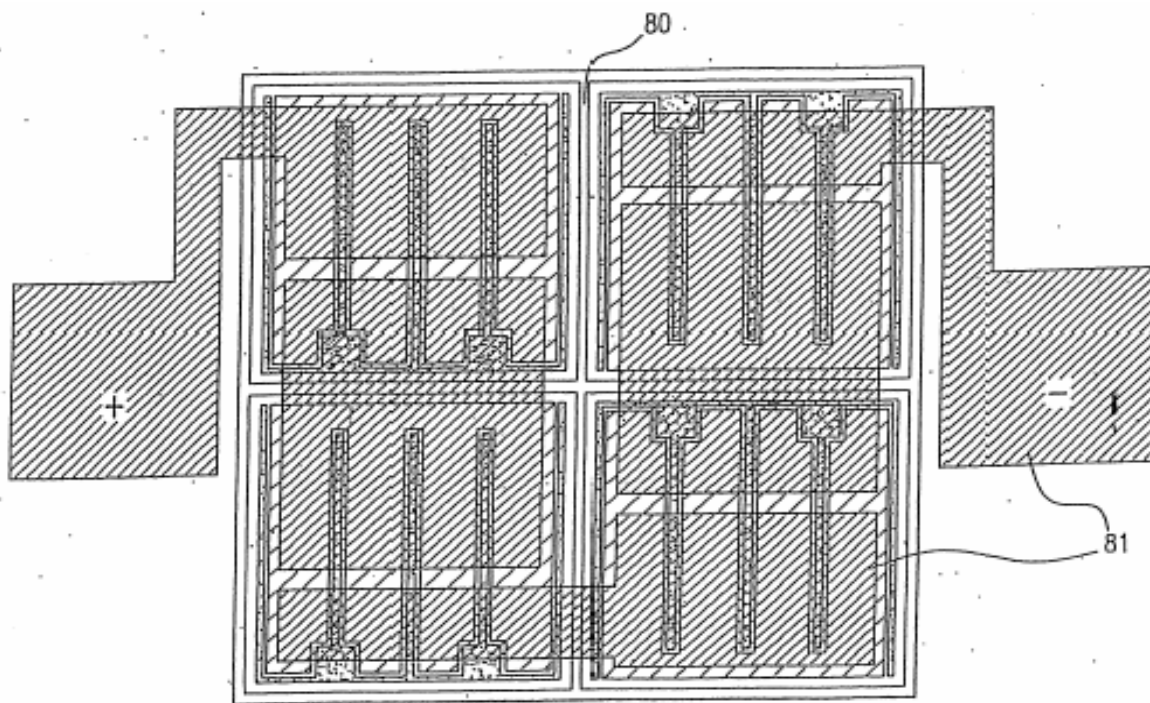


圖 17(a)

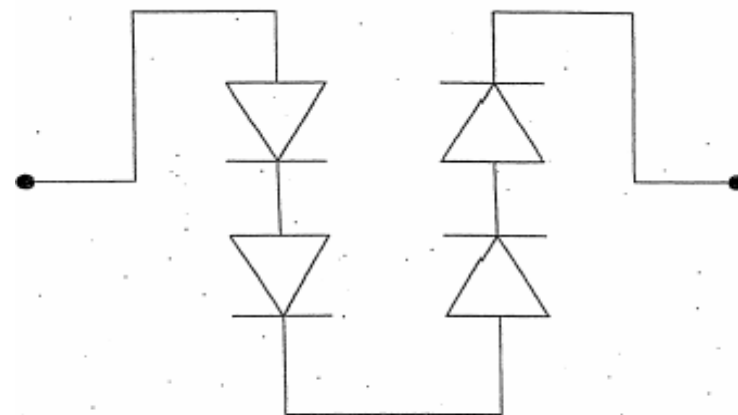
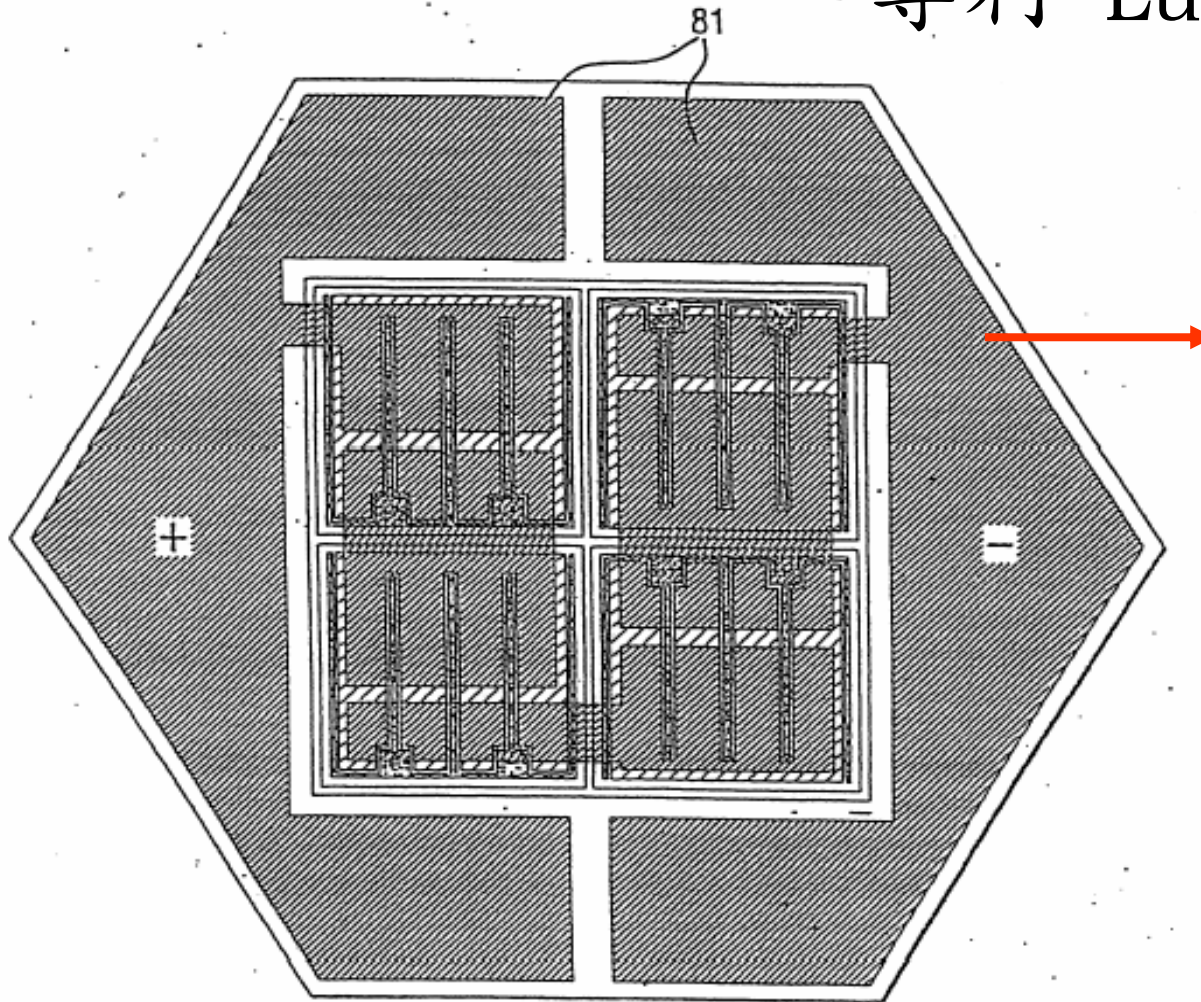


圖 17(b)

多重串聯互連發光結構



專利 Lumileds-4



Silicon

AlN

BeO

高導熱材料

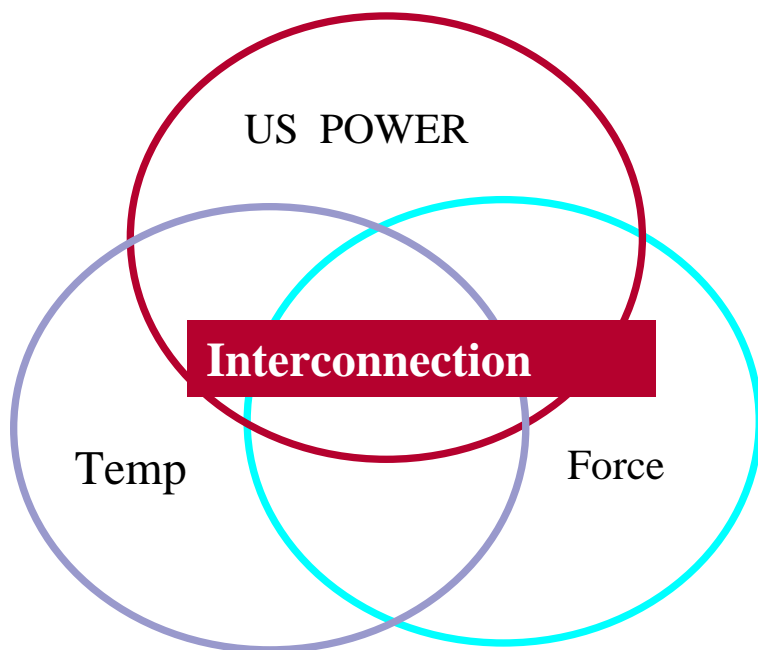
圖 18

覆晶元件的可靠度

- 覆晶製程對LED的影響
- LED的保護元件
- 大功率LED封裝

US工法上各項能量的分配狀況

The conditions of Interconnection



優先考量下壓力能量

- 適用Hi pin count
- LSI面積較大者

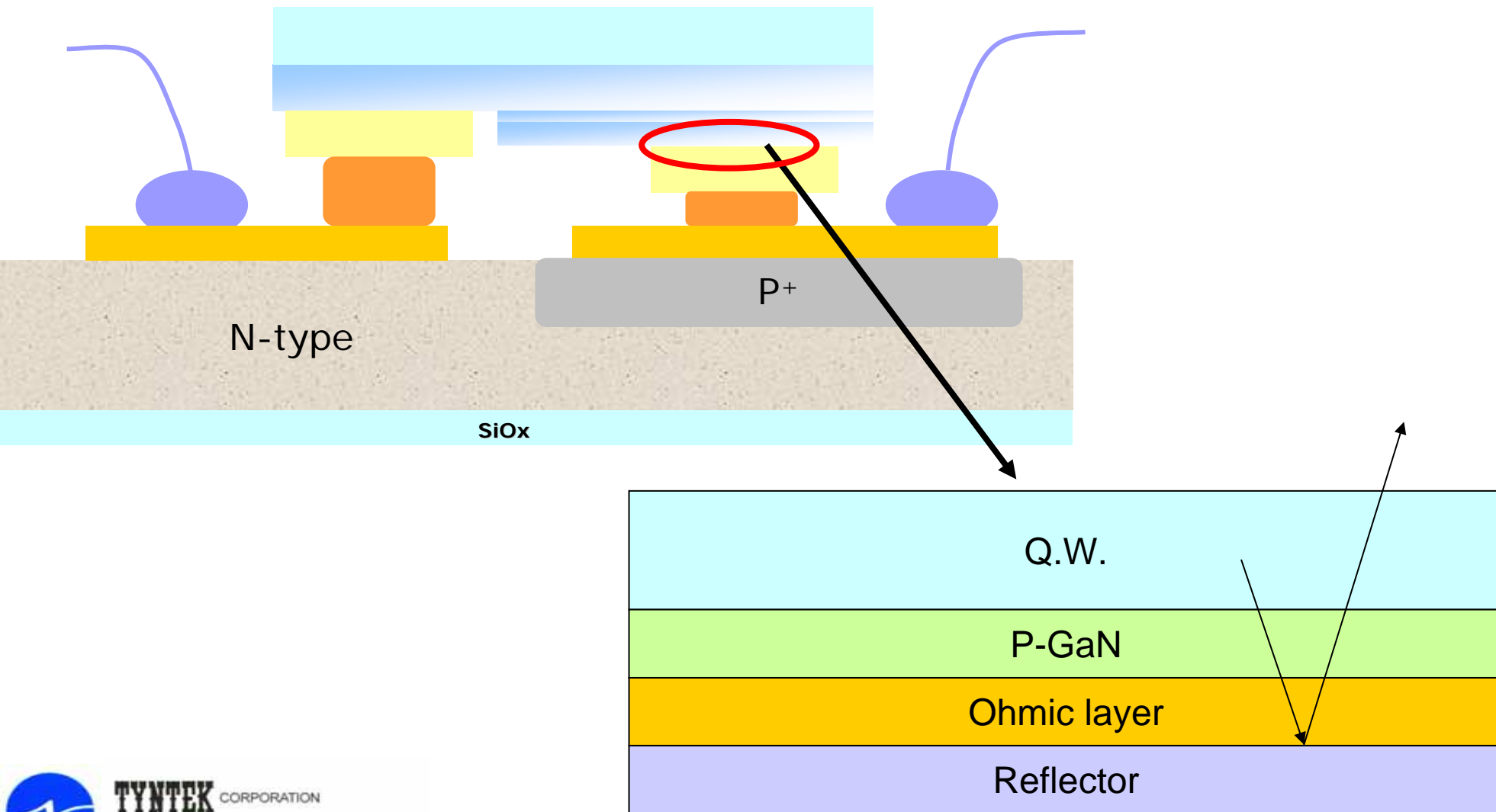
優先考量藉由溫度能量

- 增加擴散程度，使接合強度增加

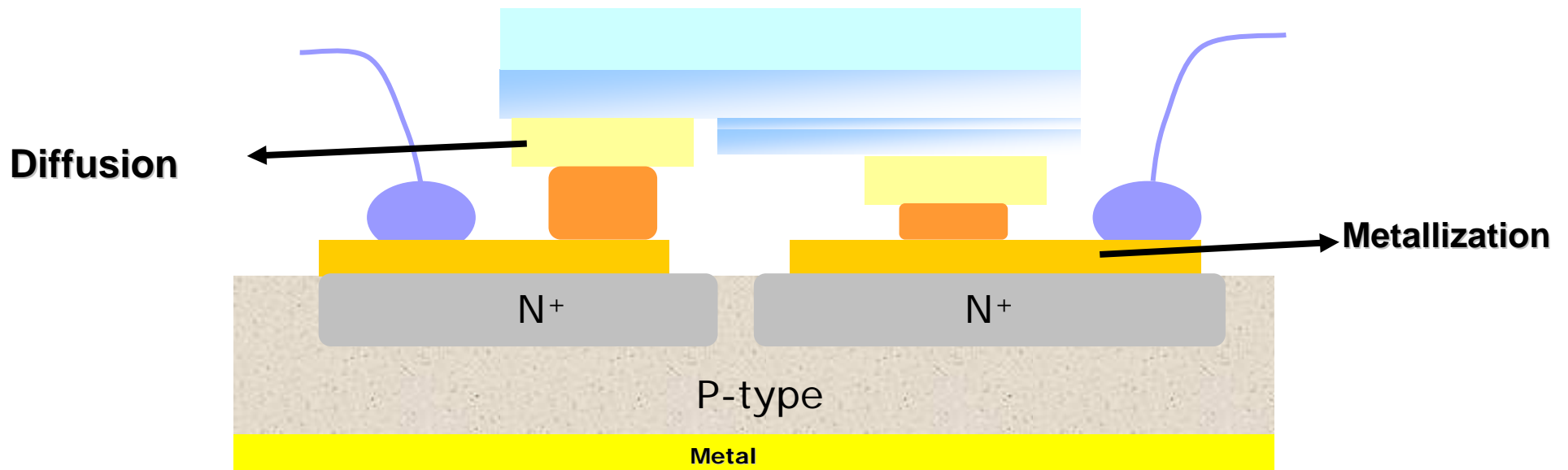
優先考量US能量傳達效率

- 適用小chip / fine pin count
- 在意熱衝擊所帶來的負面影響

Metallization

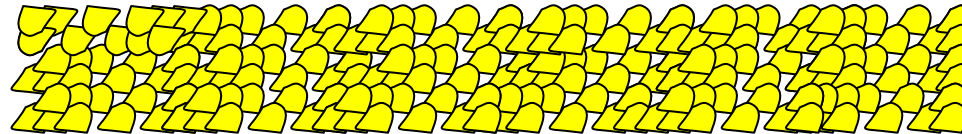


Process Issues of Flip chip

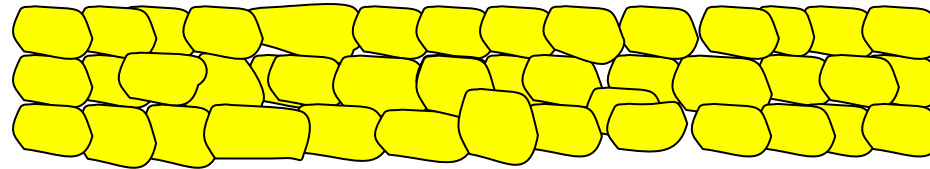


Metallization (for Flip chip)

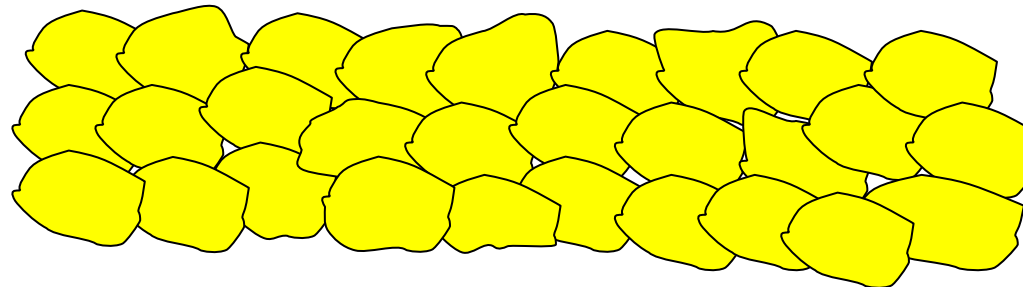
Sputter



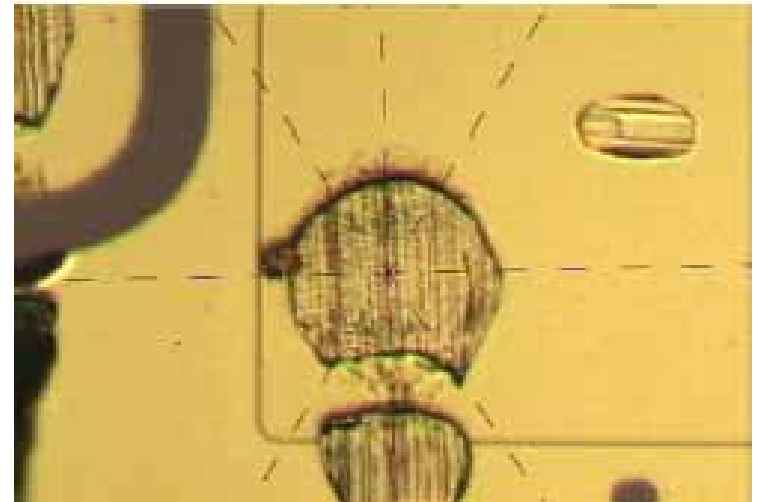
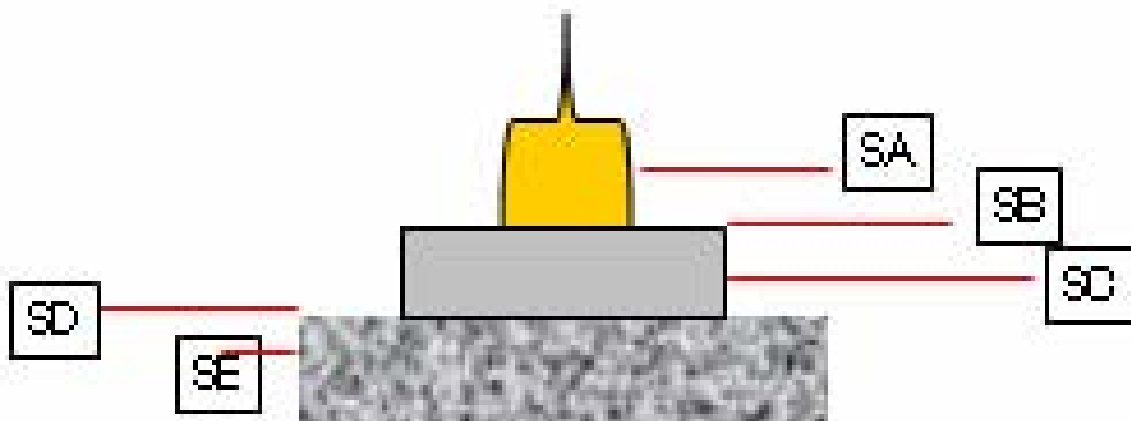
E-Gun



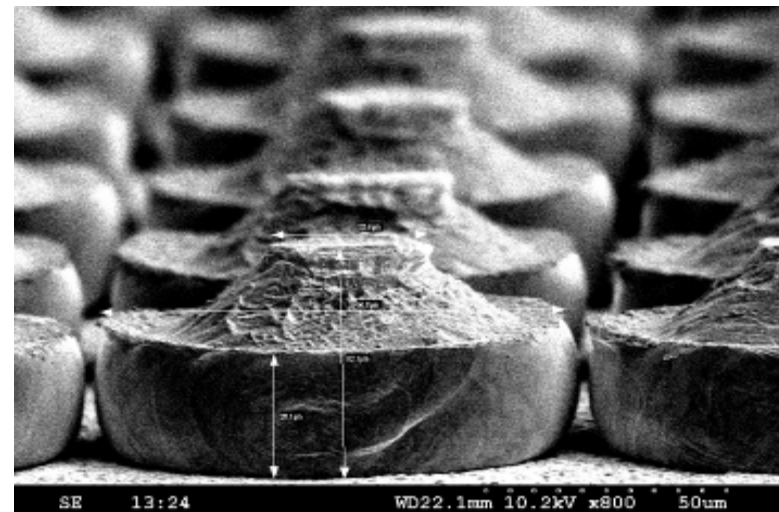
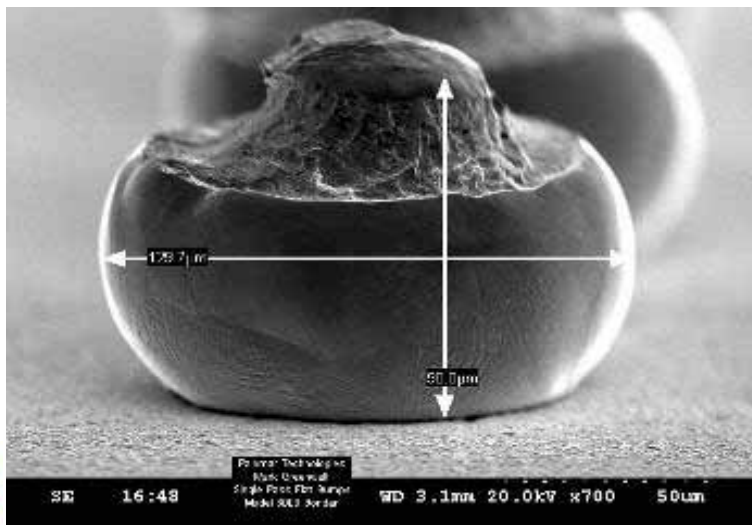
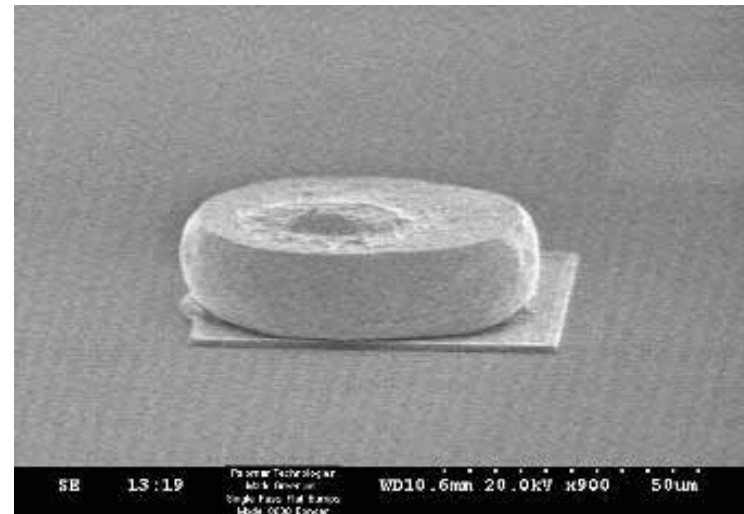
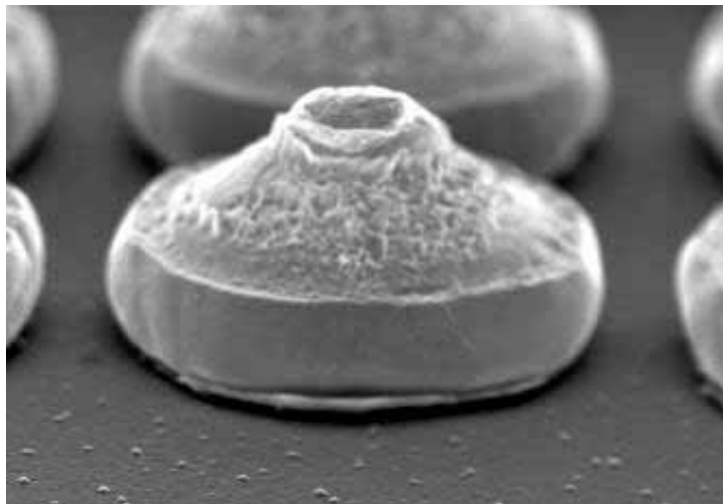
Electroplating



Stud Bumps



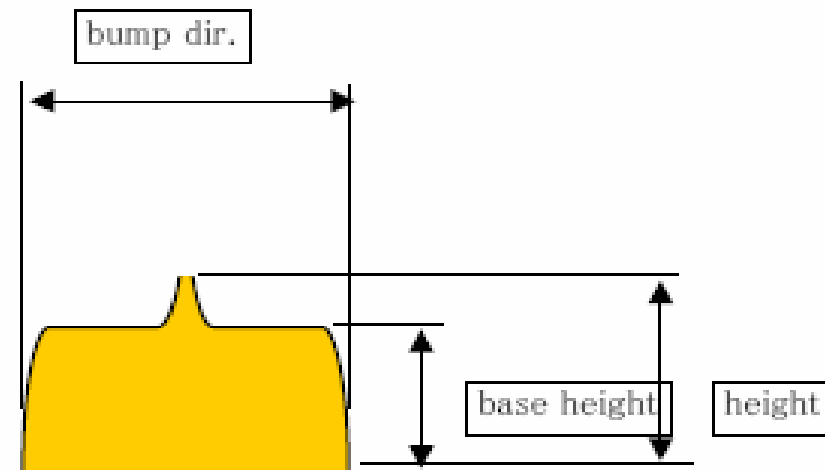
Stud Bumps from Polamar



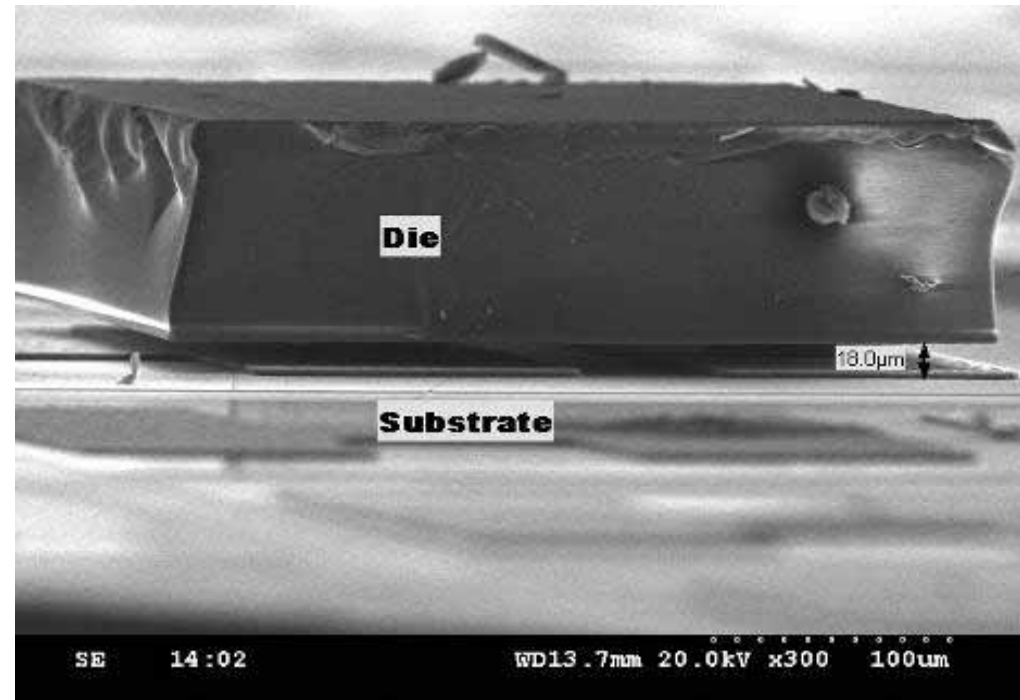
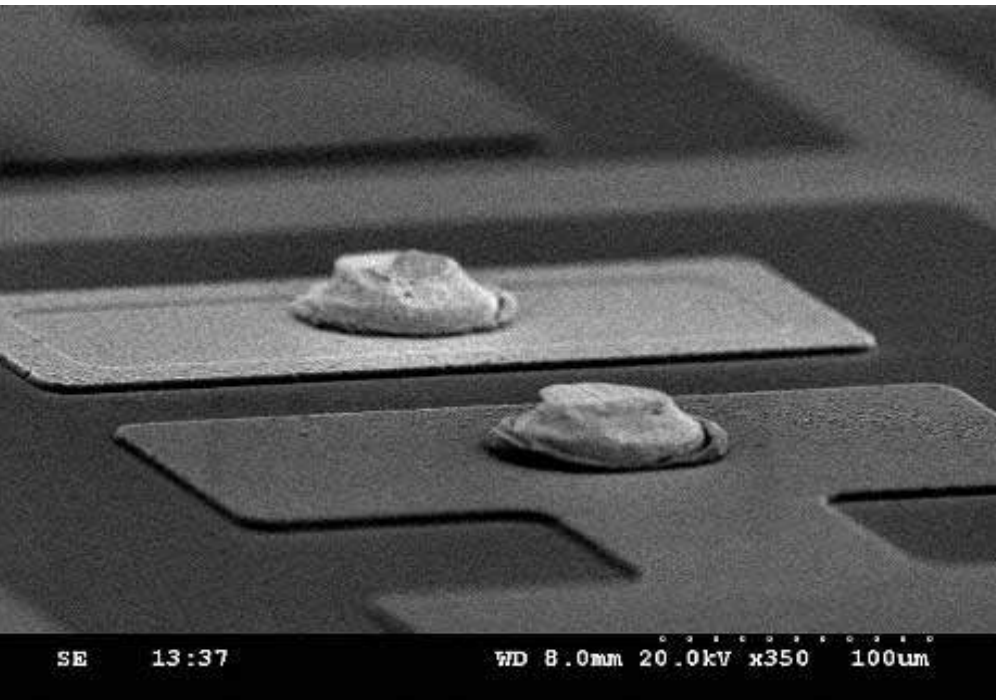
Stud Bumps

20 bumps

	Bump Dia.		Base Height (Micron)	Height (Micron)	Shear Force (Gram)	Fracture Mod
	X(Micron)	Y(Micron)				
1	88.2	97.5	12.8	80.5	79.5	SB
2	84.4	98.1	12.0	86.9	79.7	SB
3	83.1	95.9	12.1	87.3	77.2	SB
4	84.3	96.3	11.8	83.7	80.1	SB
5	84.4	94.1	12.0	84.6	69.3	SB
MAX	88.2	98.1	12.8	87.3	80.1	-
MIN	83.1	94.1	11.8	80.5	69.3	-
R	5.1	4.0	1.0	6.8	10.7	-
ave	84.9	96.4	12.1	84.6	77.1	ALL SB



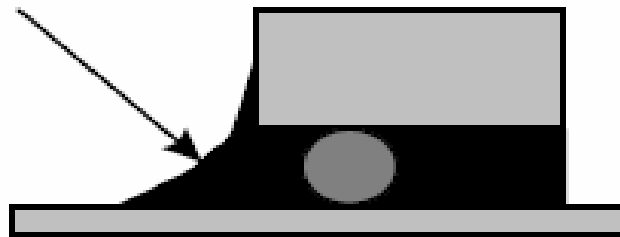
LED 與 ESD submount 的構裝



Underfill

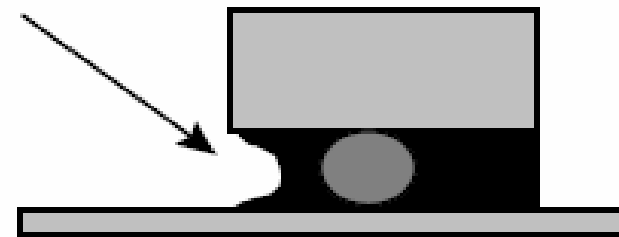
The preferred fillet on the left wicks up the side of the die and forms a slope down to the flex. If the underfill undercuts the die edge, devices were found to fail earlier than expected during thermal cycling.

Preferred
Fillet



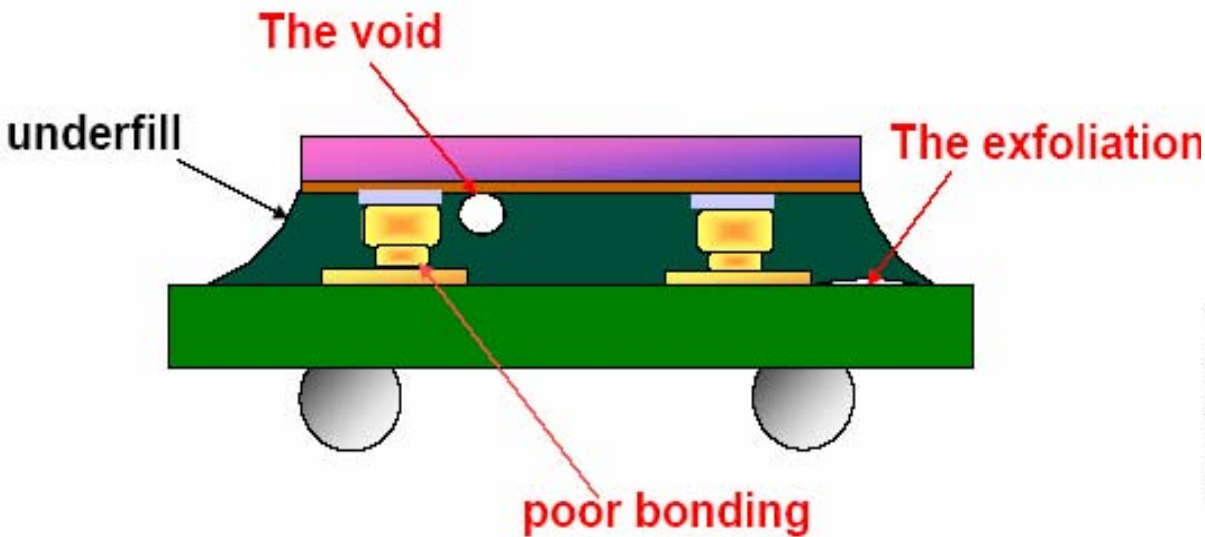
(a)

Undercut

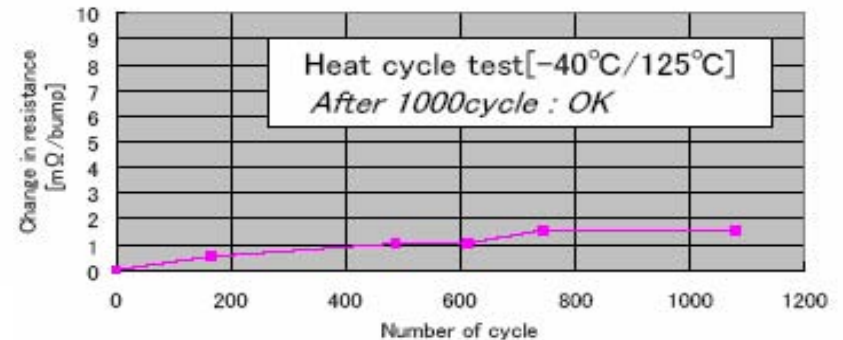
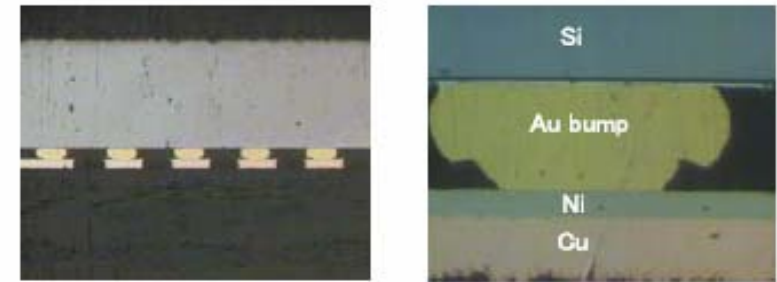


(b)

Problems of Flip chip bonding



Observed good connecting results



Stud bump Bonding

製程參數：

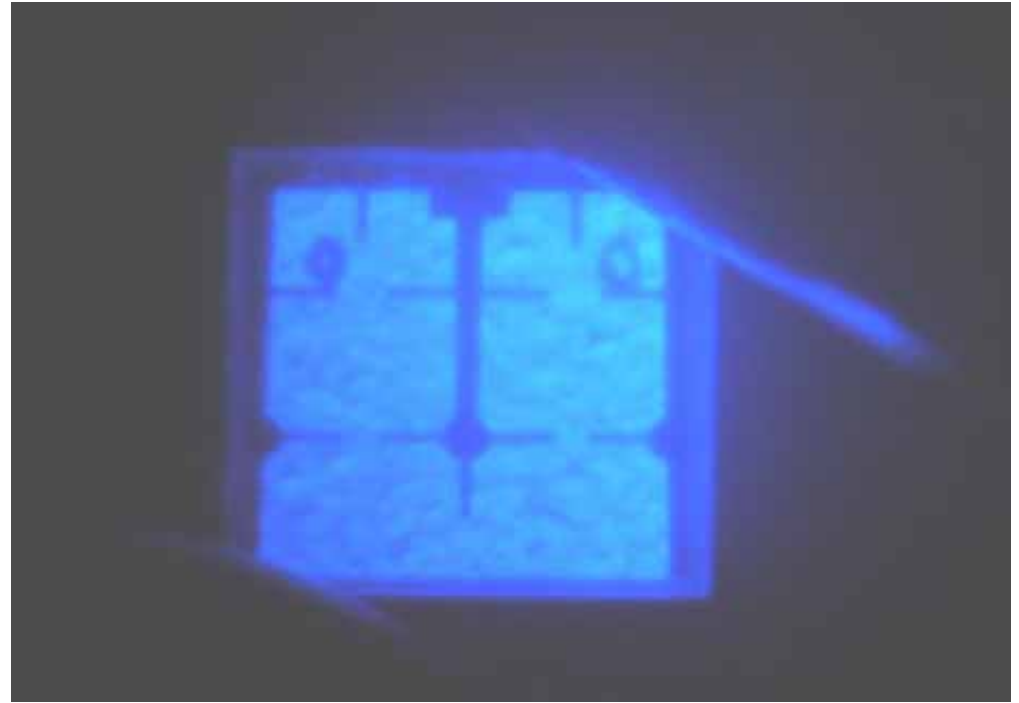
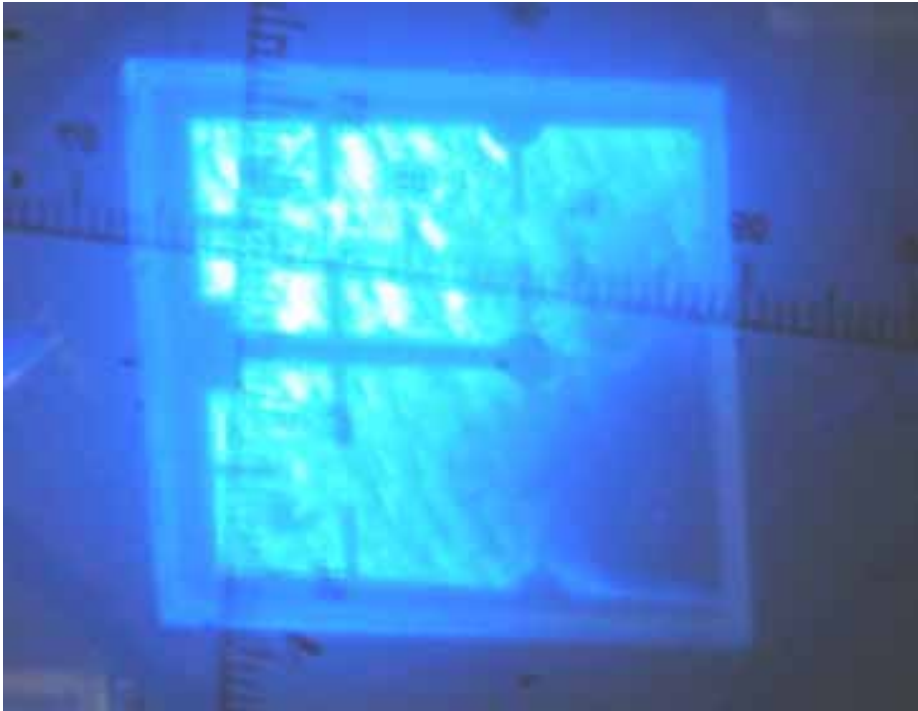
- Temperature → 可靠度,
- Bump大小 → 推力, 壽命
- Bump 形狀 → 精準度

Flip chip Bonding

製程參數:

- Temperature → Vf, 可靠度
- US-POWER → IR
- 最大下壓力 → IR, 偏移

Damage from Flip chip Bonding



Key of US Flip chip

- P-Pad & N-PAD不同的薄膜(厚度, 材料...)
- 避免漏電流
- 接合時晶粒的偏移
- 晶片背面的均勻性(不同的超音波傳遞)
- 接合材料的可靠度(擴散率的發生)
- 接合後光電性的改變
- 晶粒切割時造成晶粒不平整及汙染

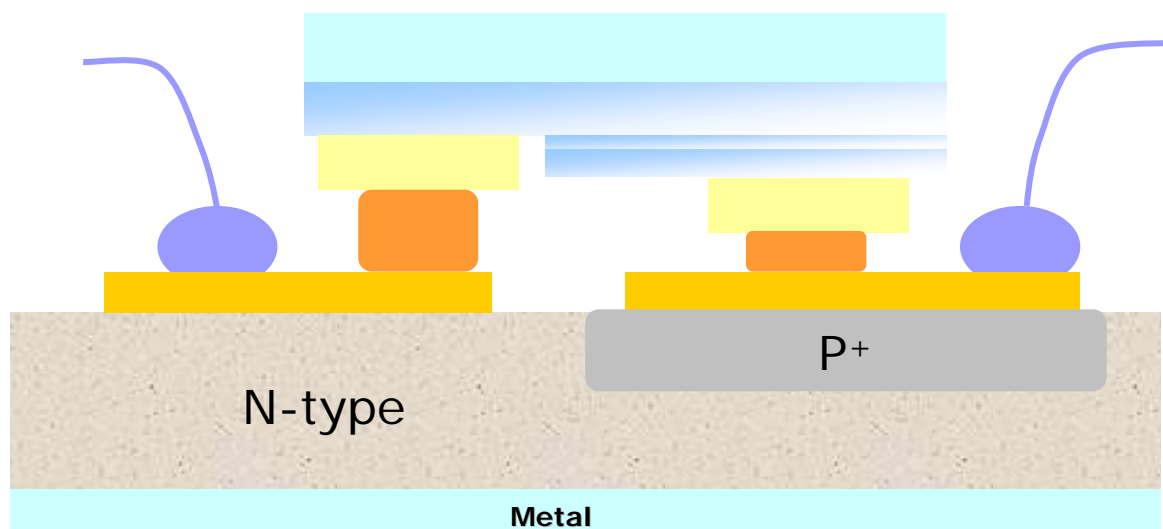
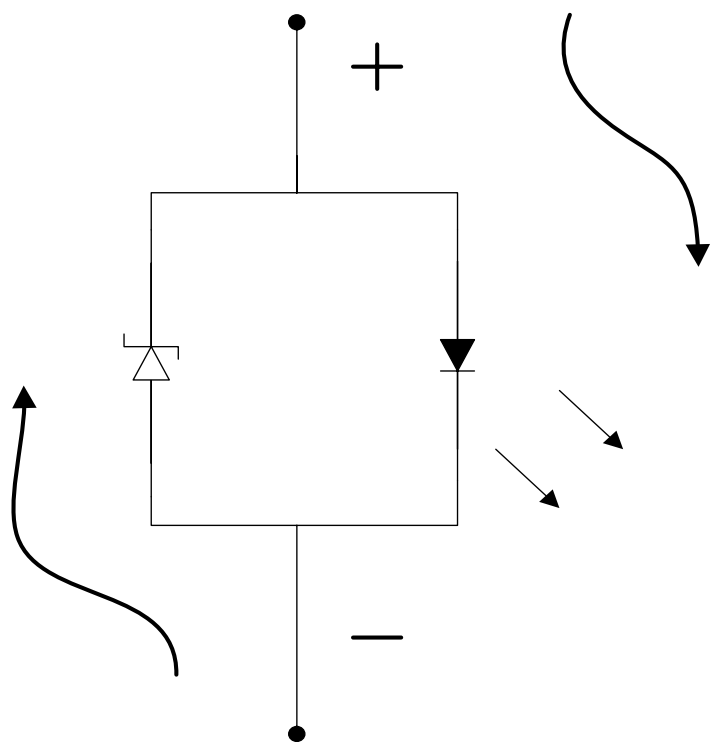


LED的可靠度

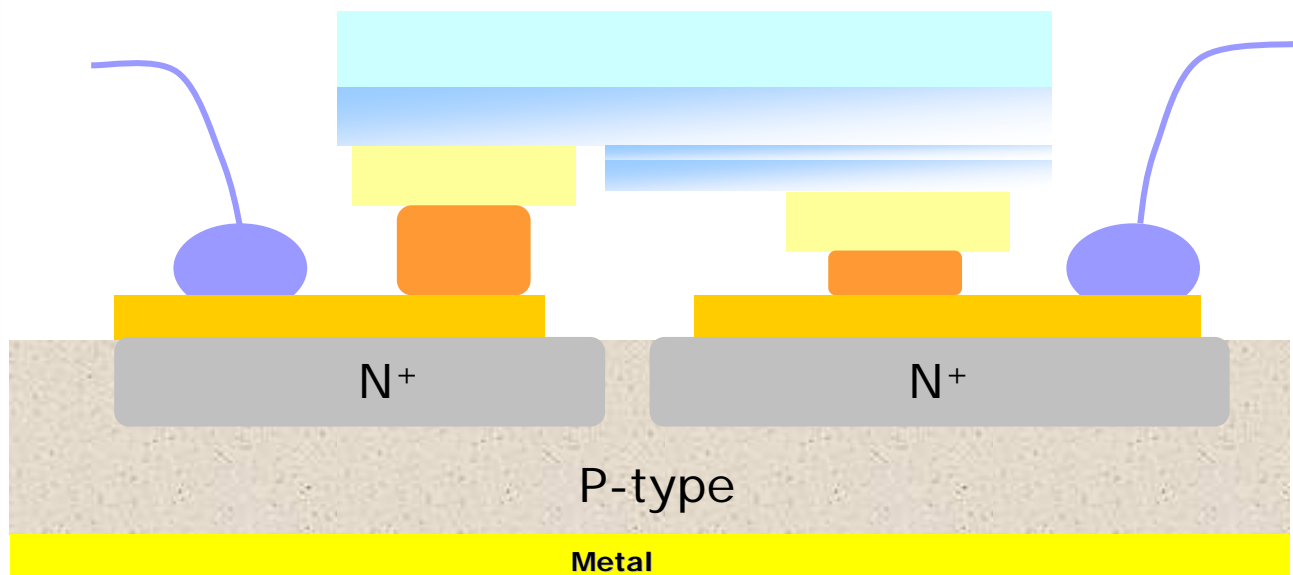
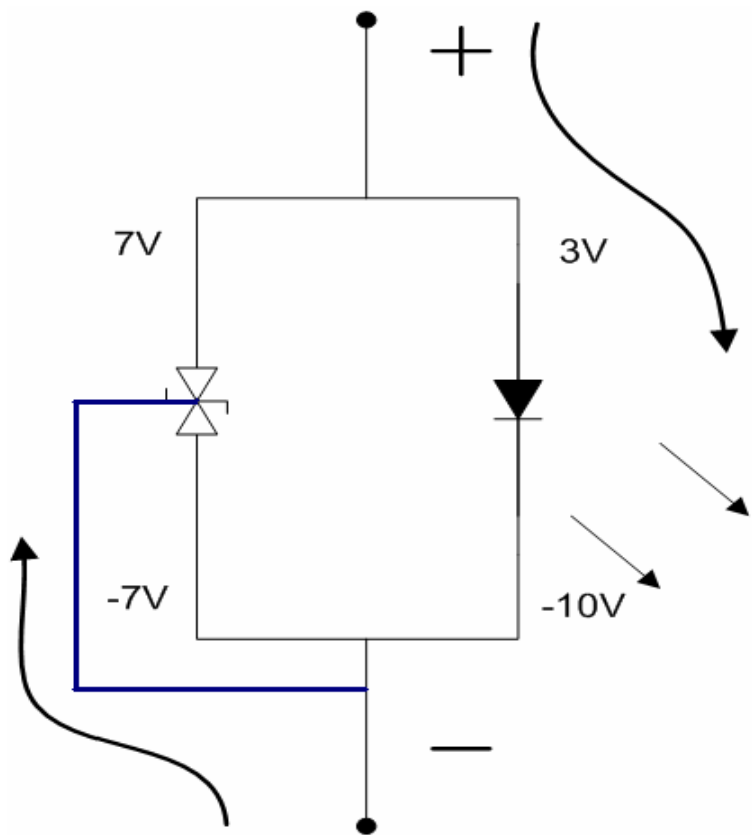
失效原因：

- 漏電流(缺陷)
- 增進亮度(P-layer)
- 熱(應力)
- 封裝失效(ESD防護; 污染; 打線失效)

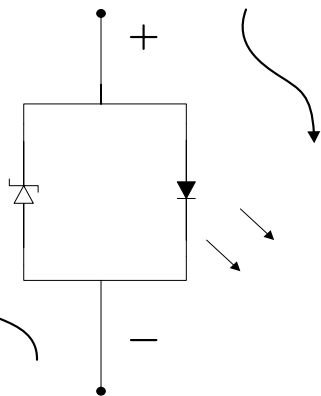
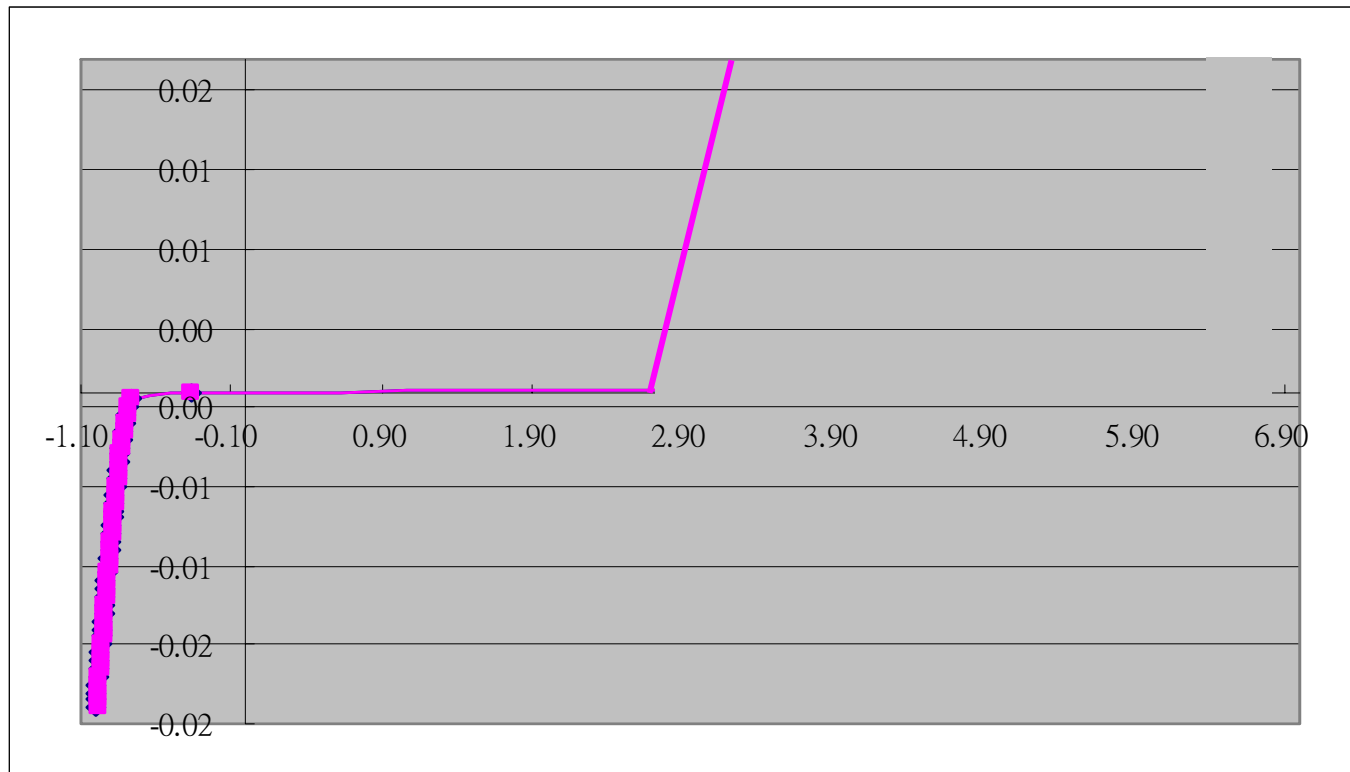
單向Zener Diode保護



雙向Zener Diode保護

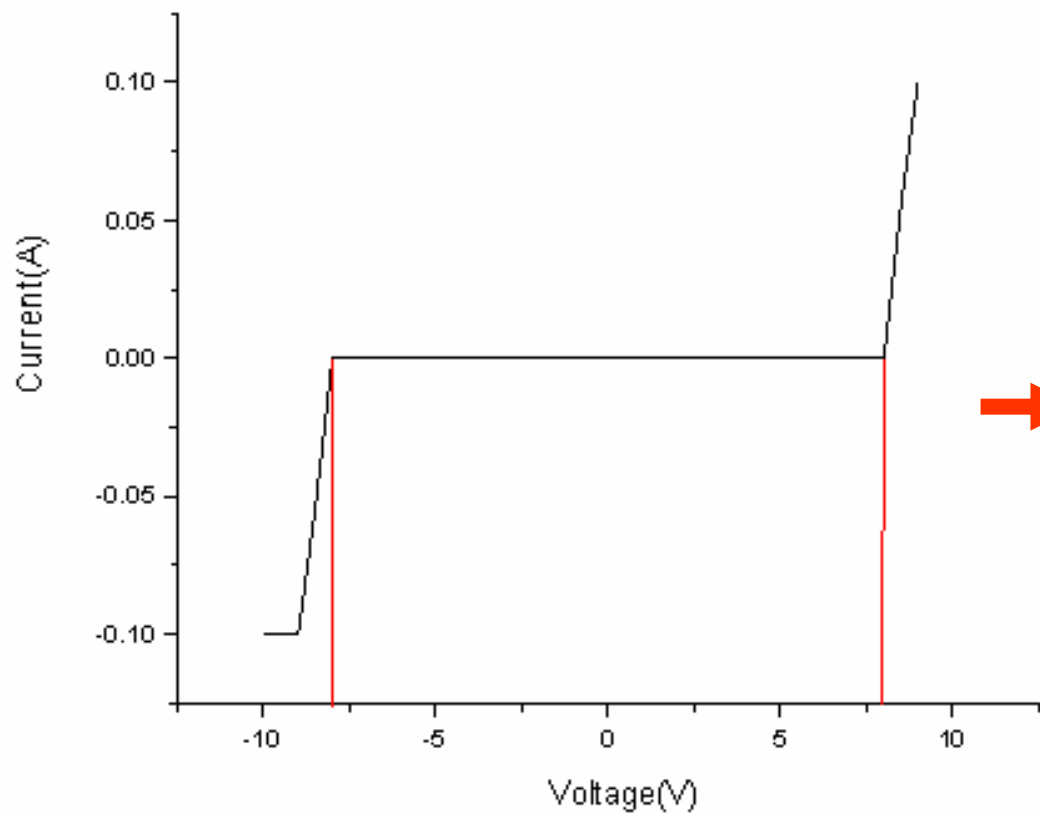


ESD Submount IV curve

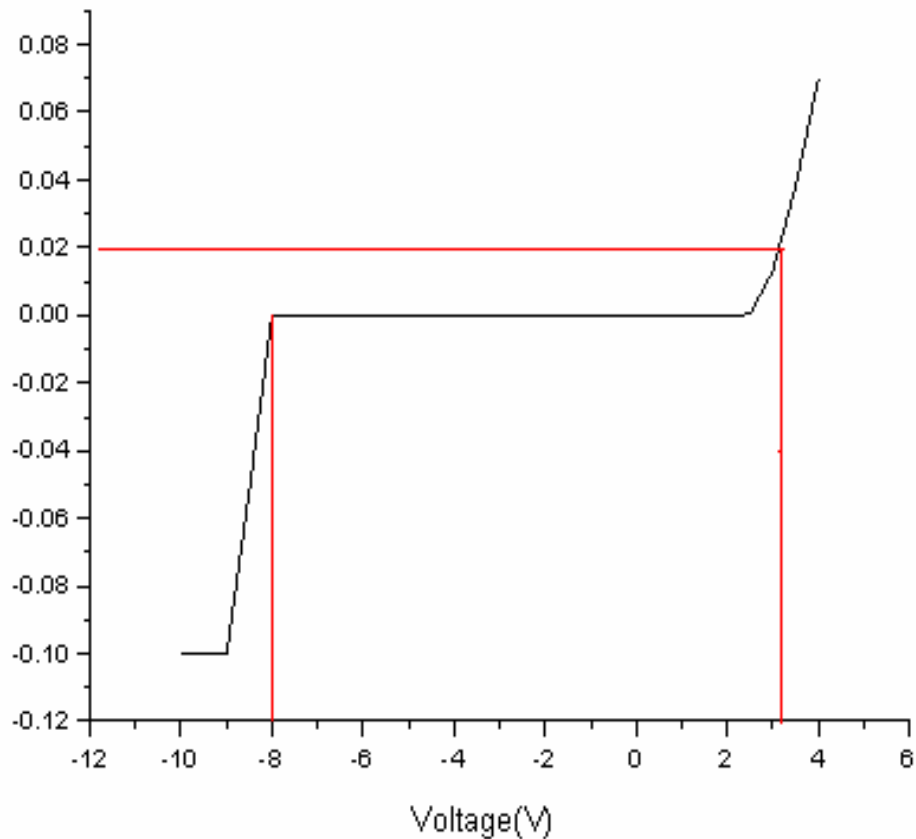


單向Zener

雙向Zener



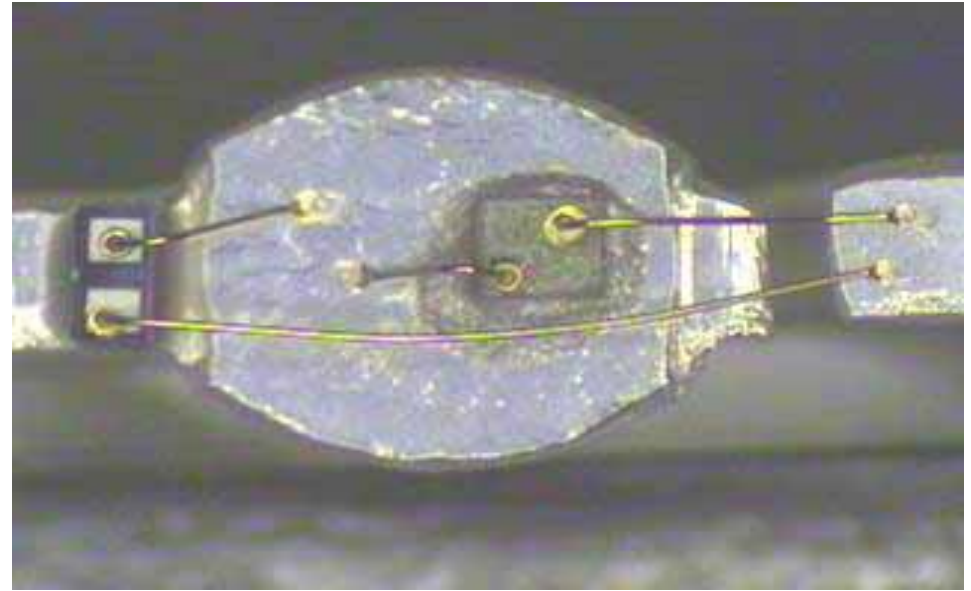
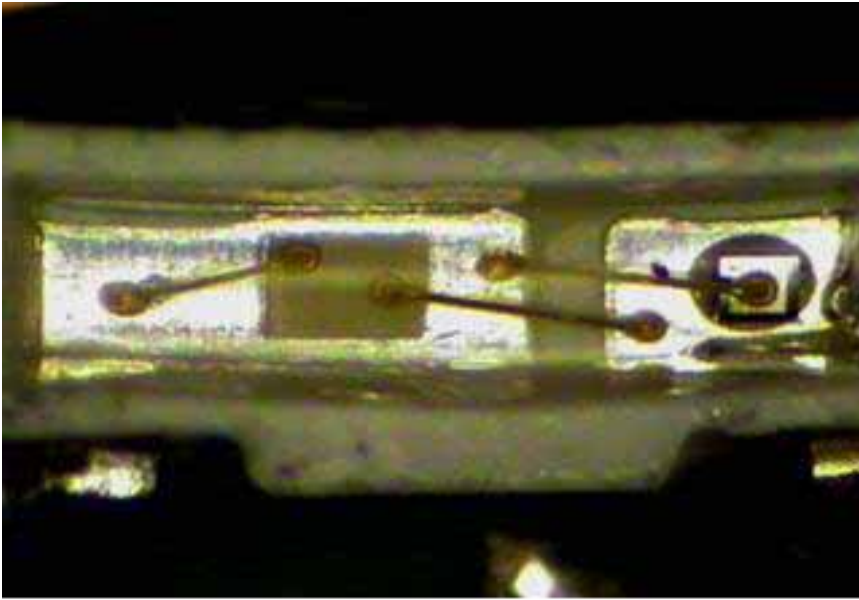
Submount IV curve



14mil Flip chip IV curve



Zener Diode打線示意圖



ESD Testing

HBM

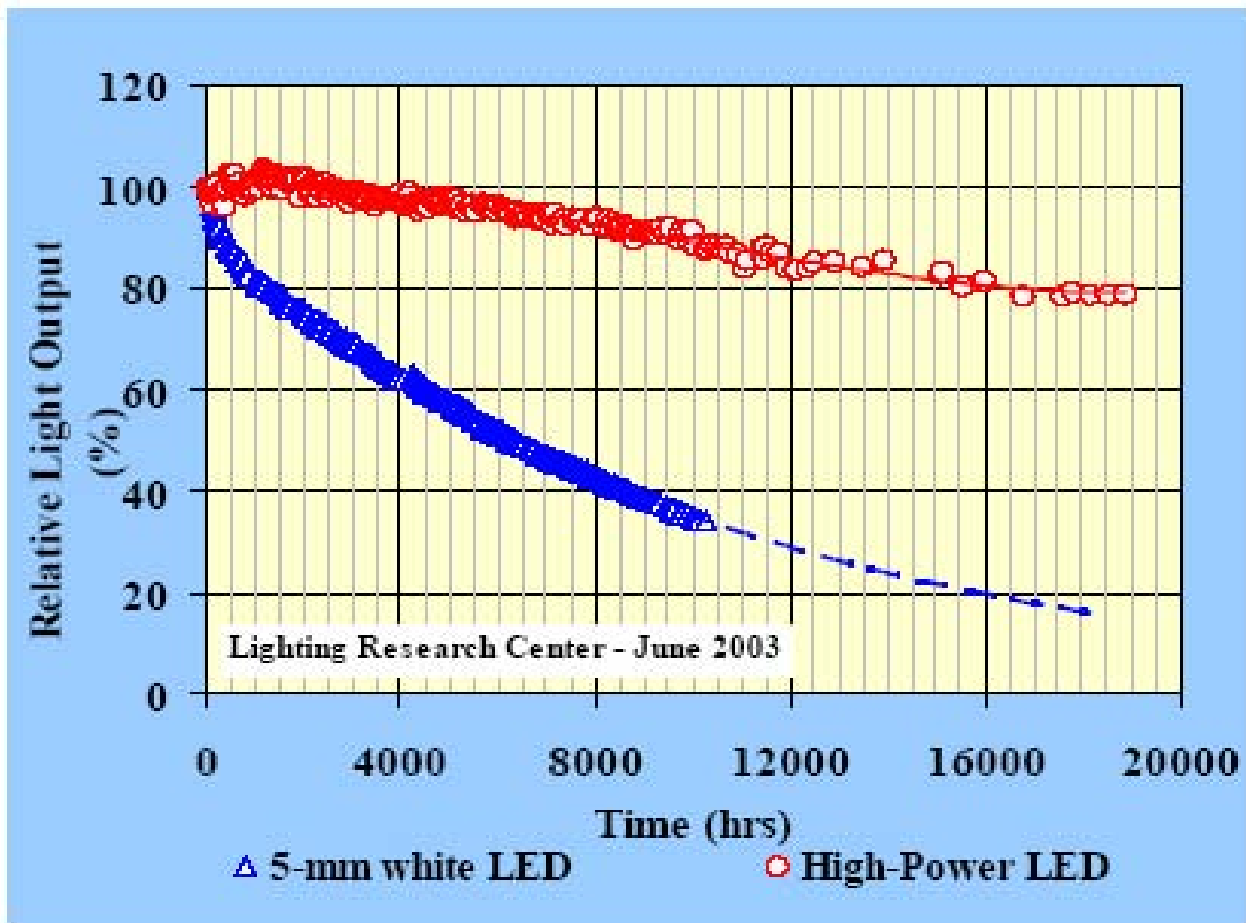
IR@5V < 10 μ A

LED規格	Bule chip without Ziner diode									
HBM(V)	1	2	3	4	5	6	7	8	9	10
100	×		×	×		×	×	×	×	×
200		×			×					
300										
400										
500										
600										
700										
800										
1K										
1.1K										
1.2K										
1.3K										

LED規格	blue chip with Ziner diode						
HBM(V)	1	2	3	4	5		
2.5K							
3K							
3.5K							
4K							
4.5K							
5K							
5.5K							
6K							
6.5K							
7.5K							
8K	○	○	○	○	○		



Lumileds LED



○ High-Power LED



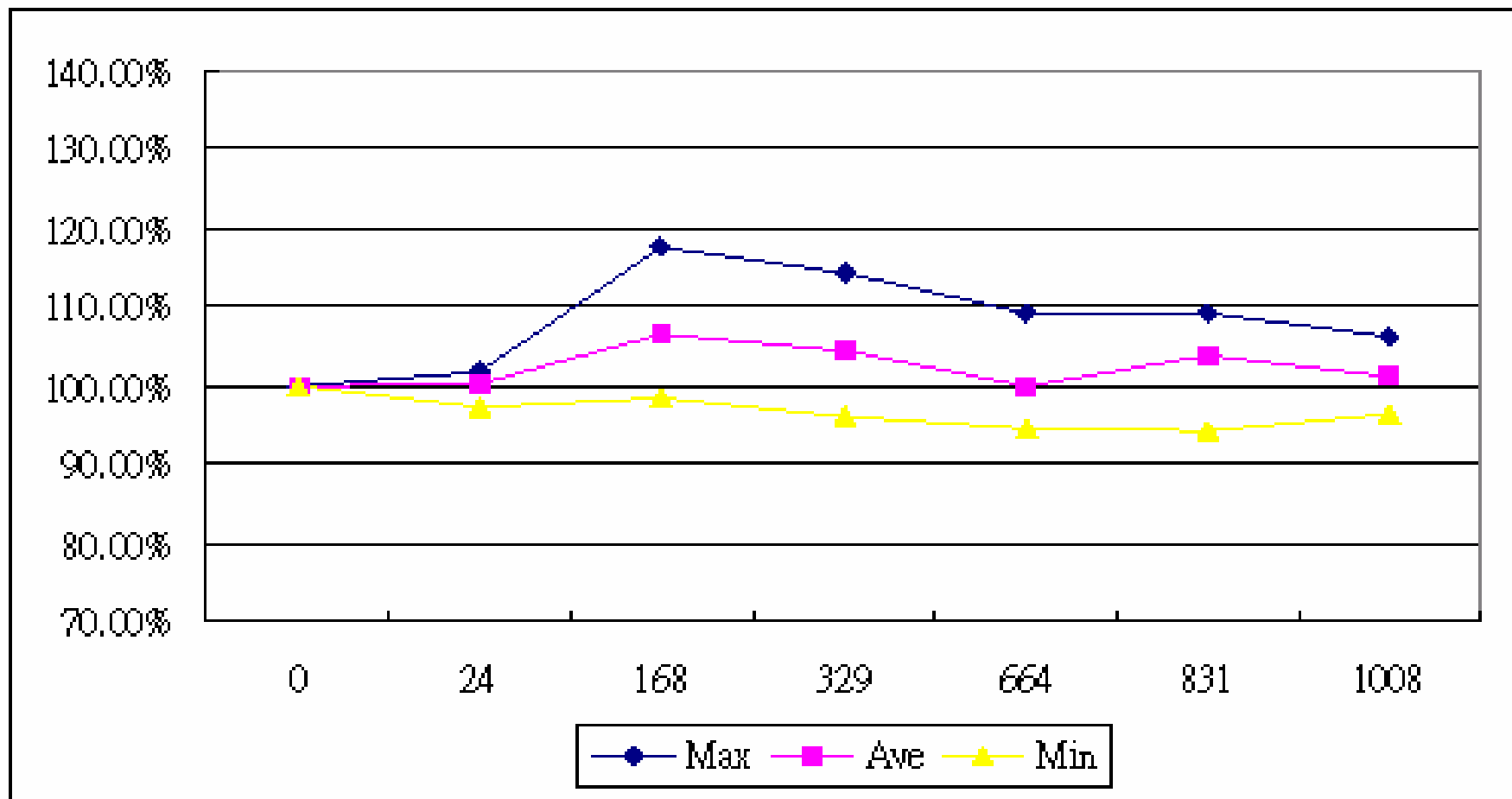
△ 5-mm white LED



Courtesy Lighting Research Center



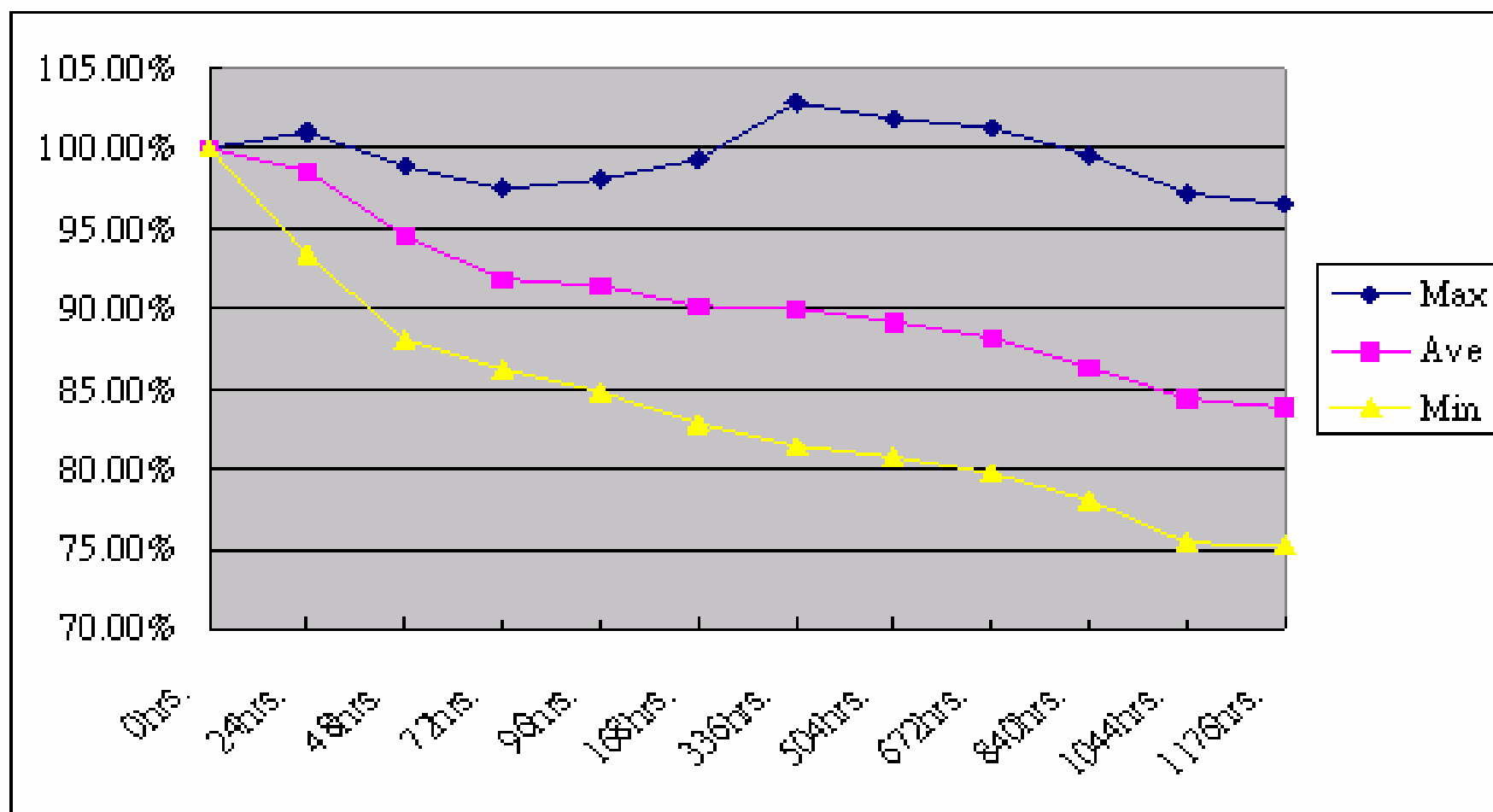
High Lifetime (14mil Flip chip)



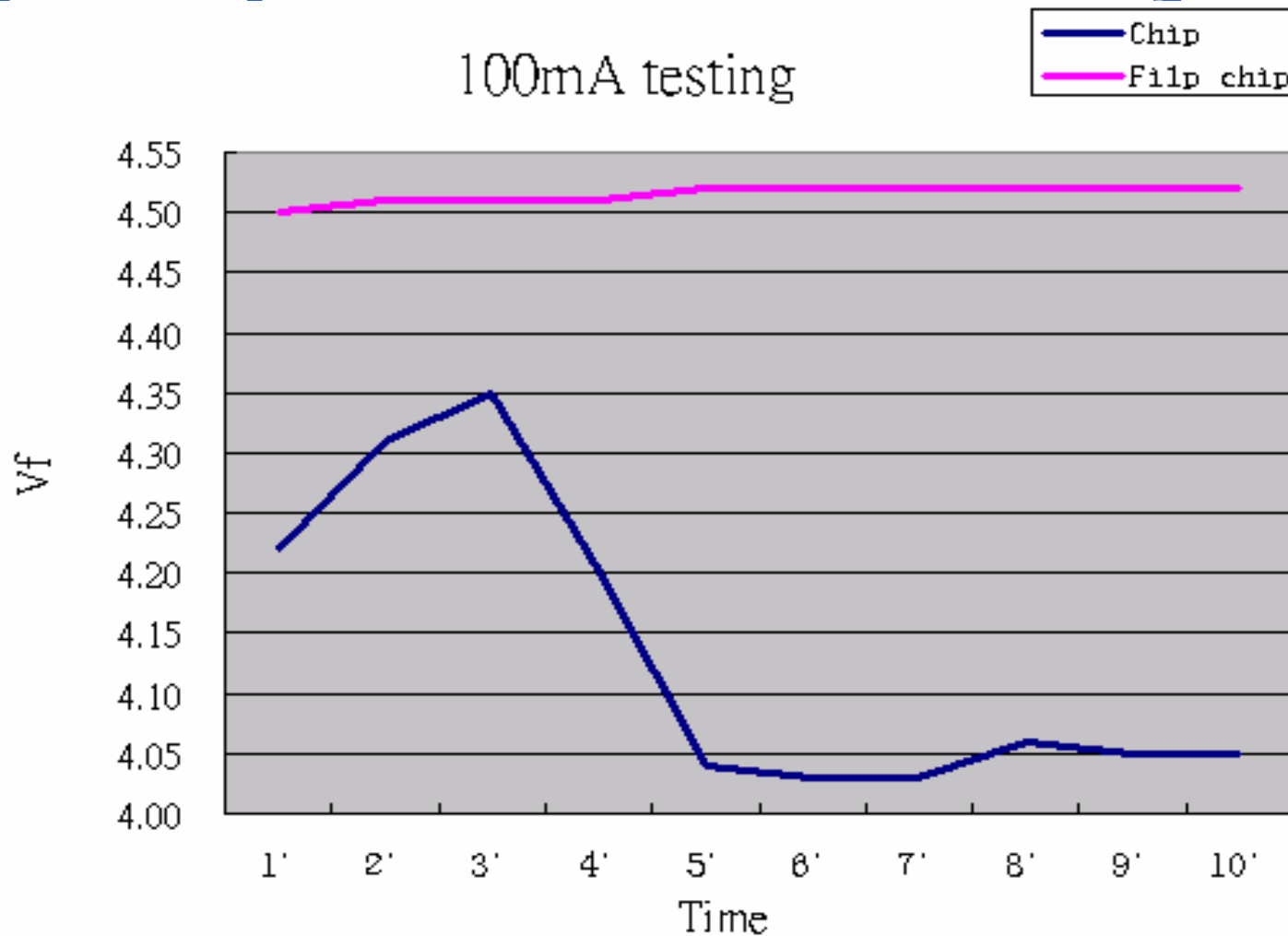
Test of 1008 hours



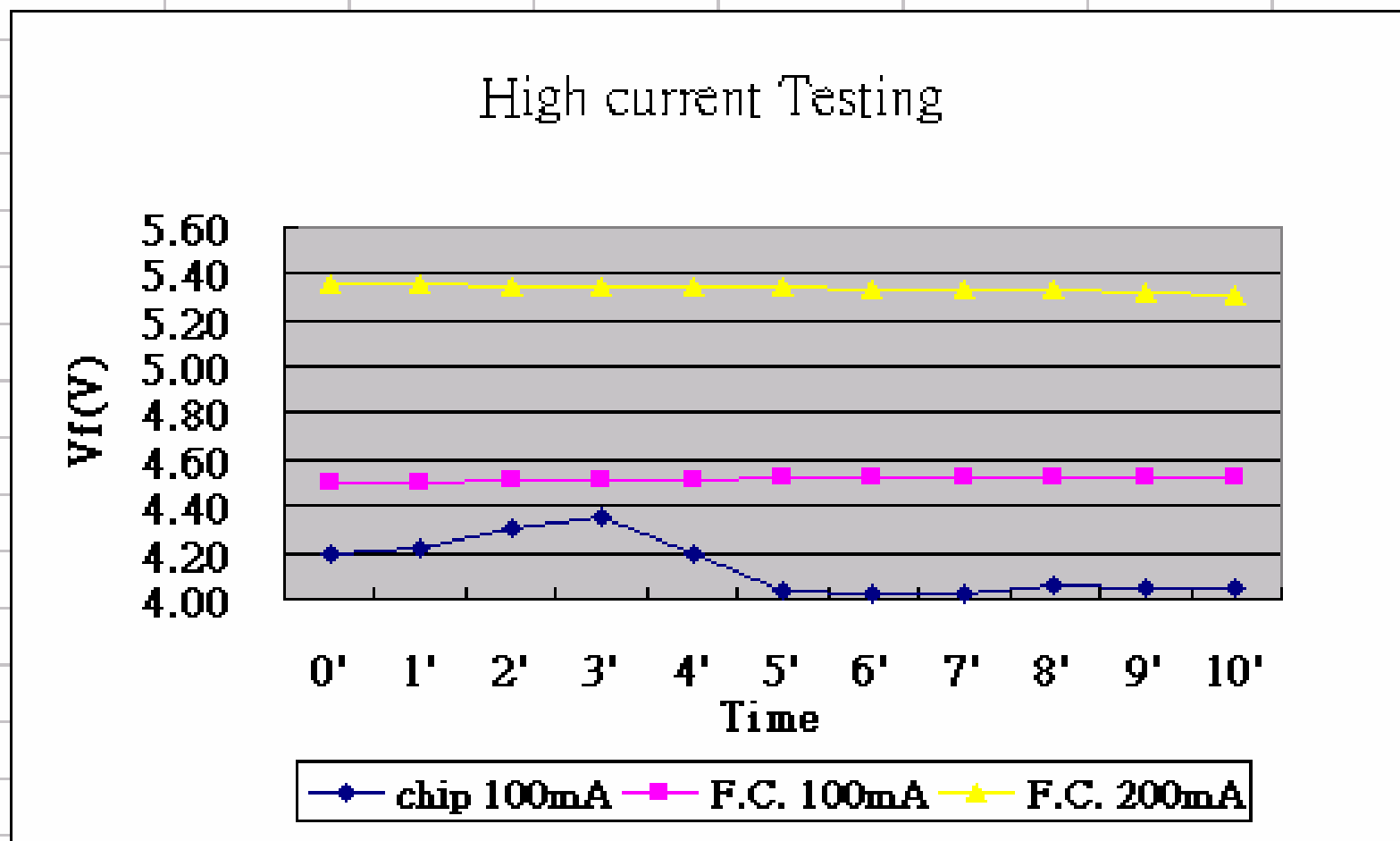
Blue chip without Zener diode



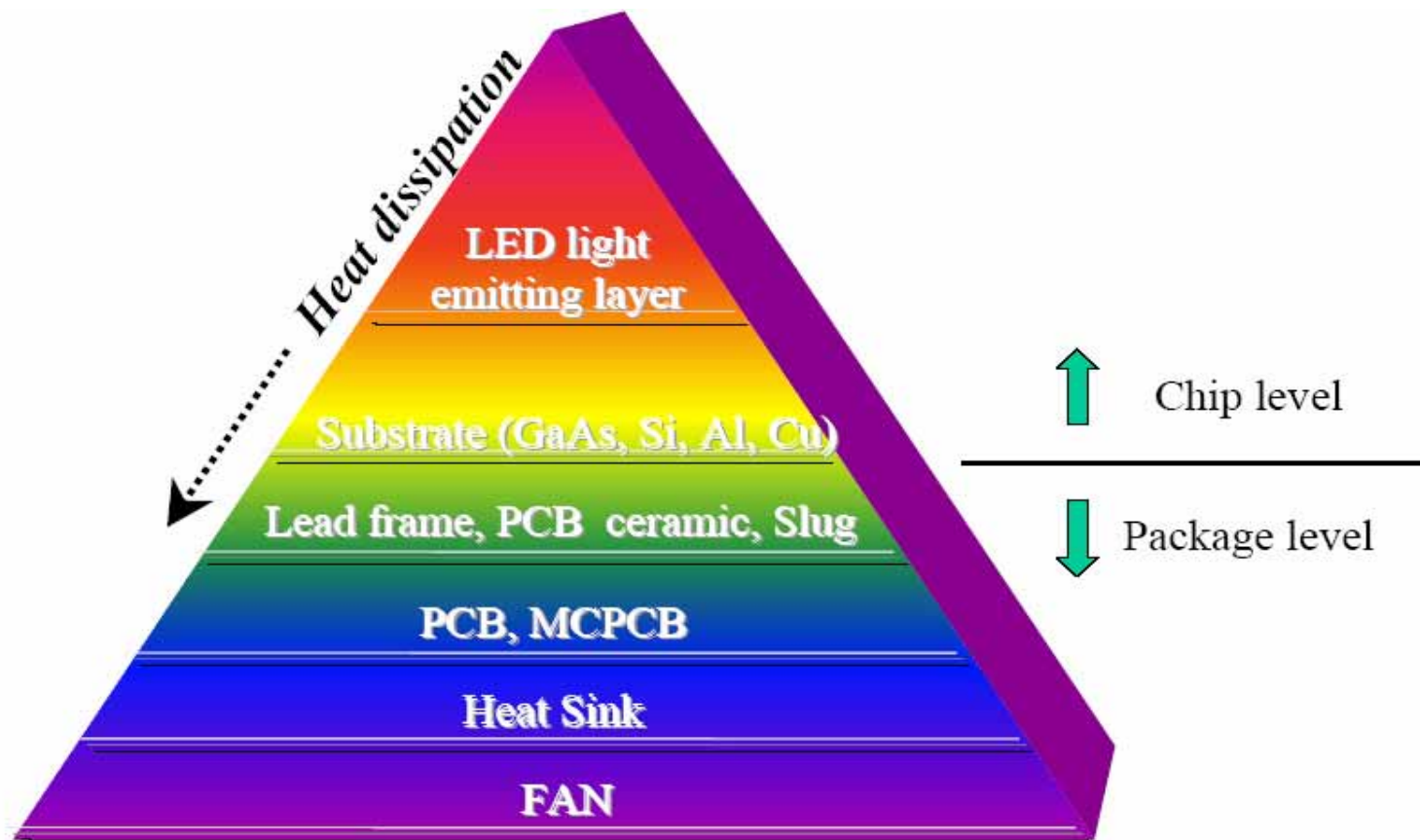
Flip chip Thermal Stability



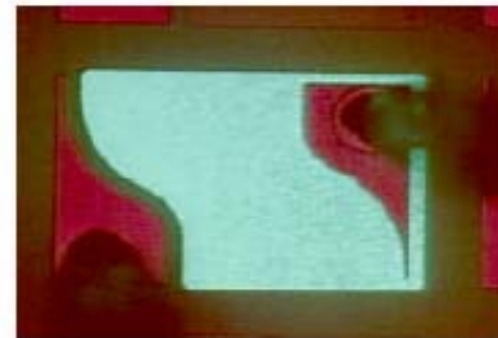
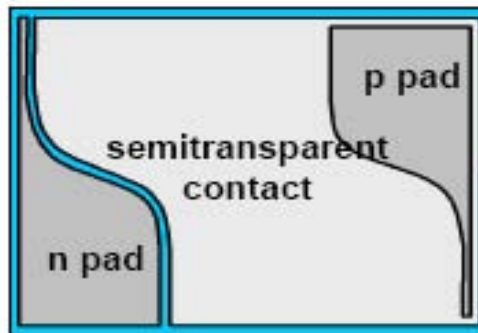
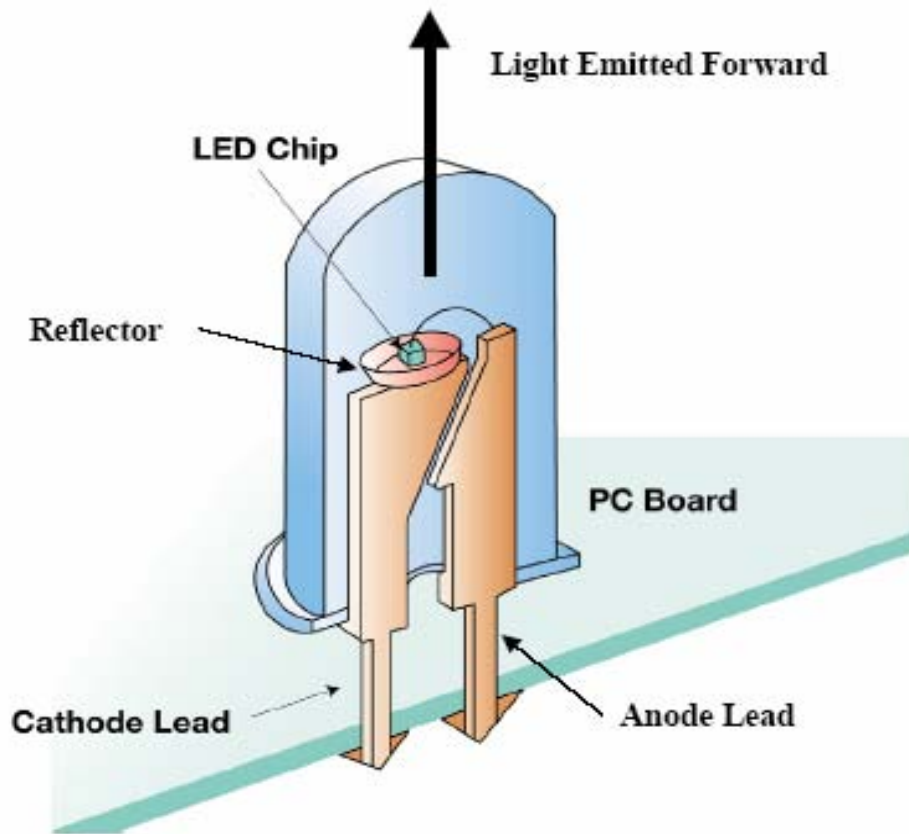
High current Testing (Chip & FC)



大功率LED封裝

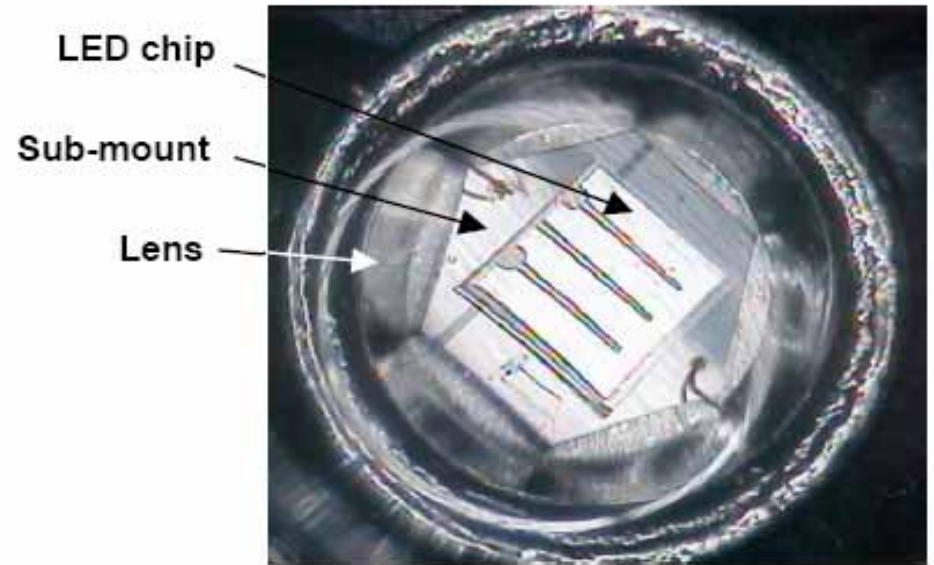
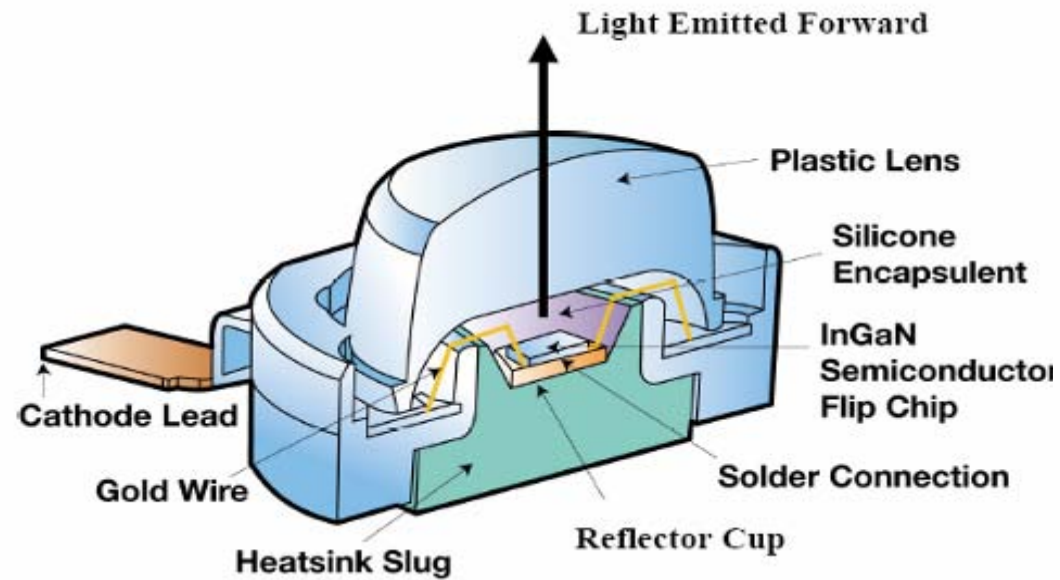


a typical indicator LED



Junction area $\sim 0.06\text{mm}^2$

Power LED



From Lumileds

Thermal Resistance Model

$$R_{\Theta} \text{ Junction - Ambient} = \frac{\Delta T_{\text{Junction - Ambient}}}{P_d}$$

Where:

$$\Delta T_{\text{junct. - amb.}} = T_{\text{Junction}} - T_{\text{Ambient}} (^{\circ}\text{C})$$

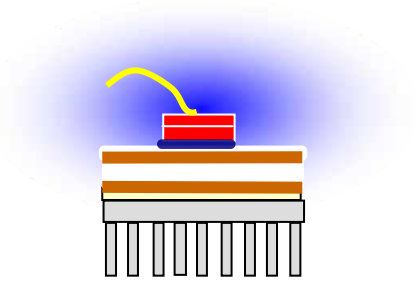
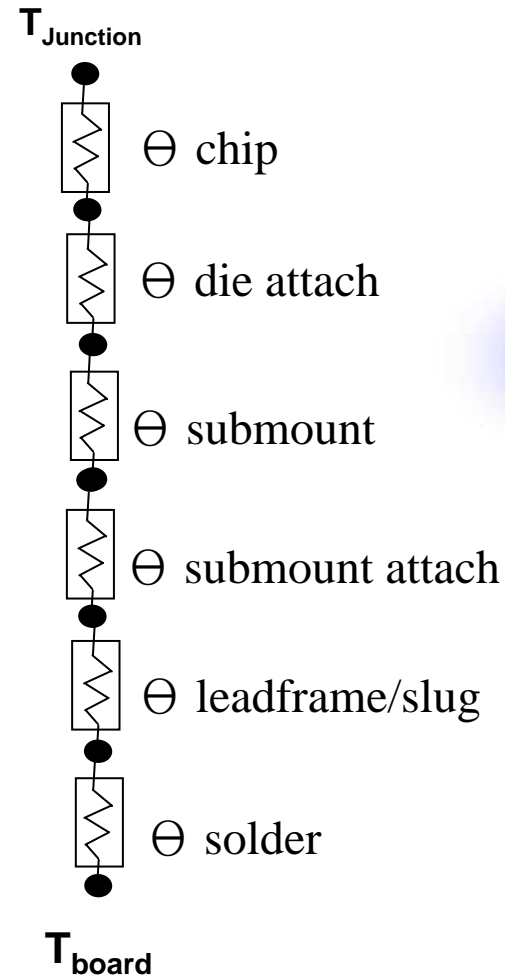
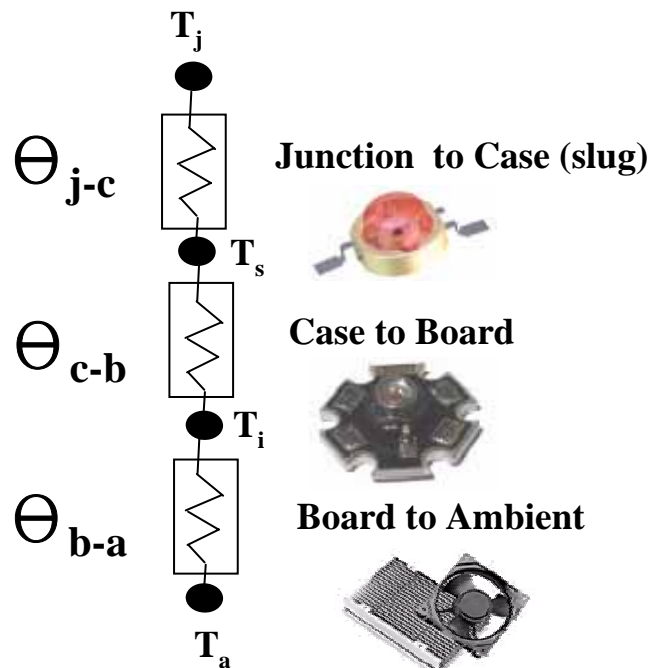
P_d = Power Dissipated (W)

P_d = Forward Current (If) * Forward Voltage (Vf)

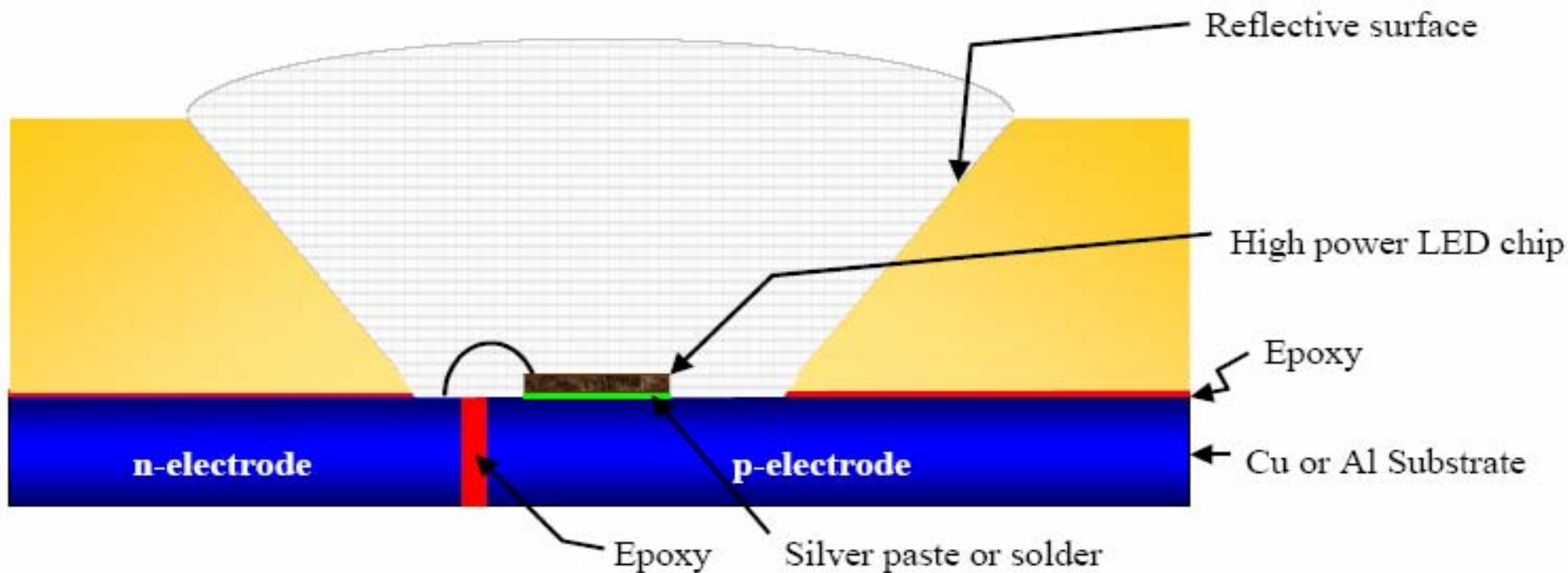
Thermal Resistance

Series $\Theta_{total} = \sum_{i=1}^n \Theta_i$

$$\Theta_{total} = \Theta_{j-c} + \Theta_{c-b} + \Theta_{b-a}$$



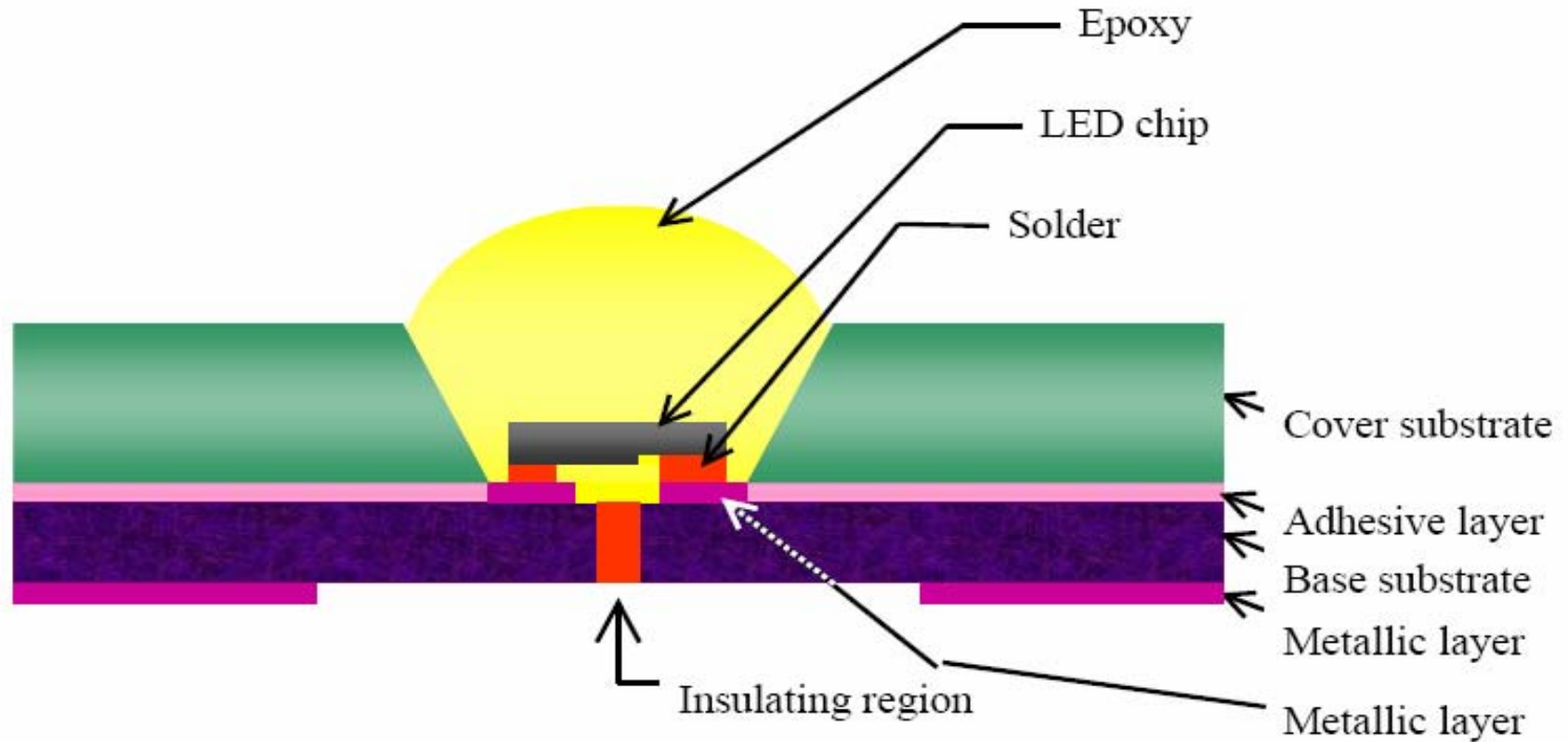
High Power LED Package Structure



For Wafer Bonding product or Flip chip



High Flux Light Emitting Diode



熱應力問題

Low-Temperature Cofired Ceramics (LTCC)



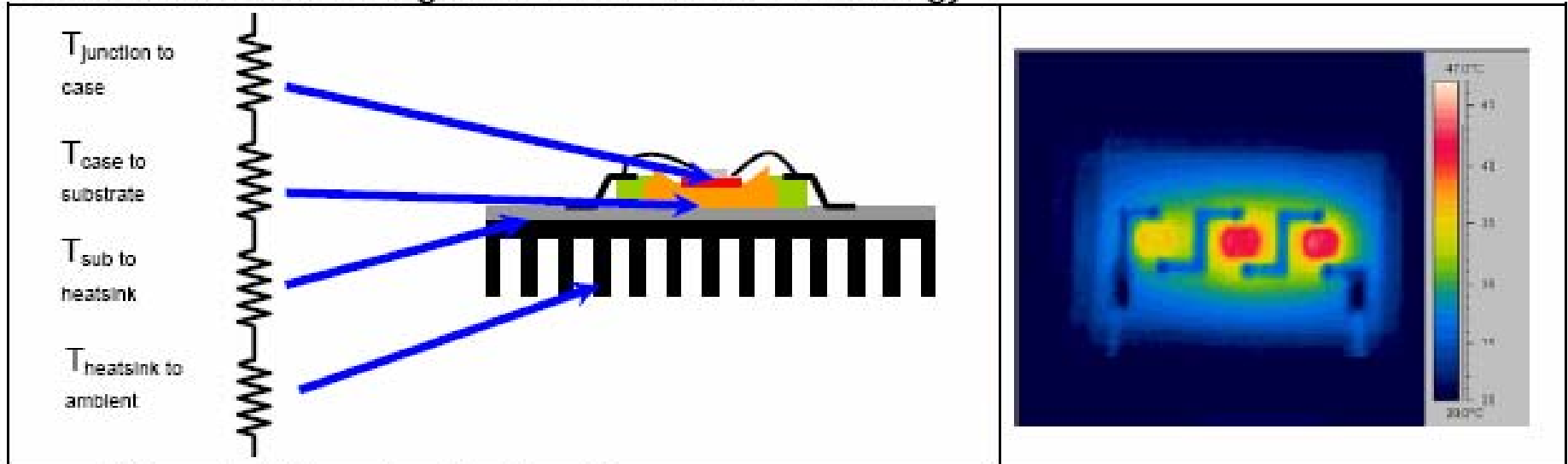
Technical Data

Part # BL-21A0-0121	Symbol	Min	Typical	Max	Unit
Wavelength	λ	613	618	623	nm
Voltage*	V_F	-	6.7	-	V
Test Current	I_F	-	2.1	-	A
Power*	P	-	13.6	-	W
Luminous Flux*	Φ_V	-	270	-	lm
Thermal Resistance	T_R	-	2.25	3	$^{\circ}\text{C}/\text{W}$

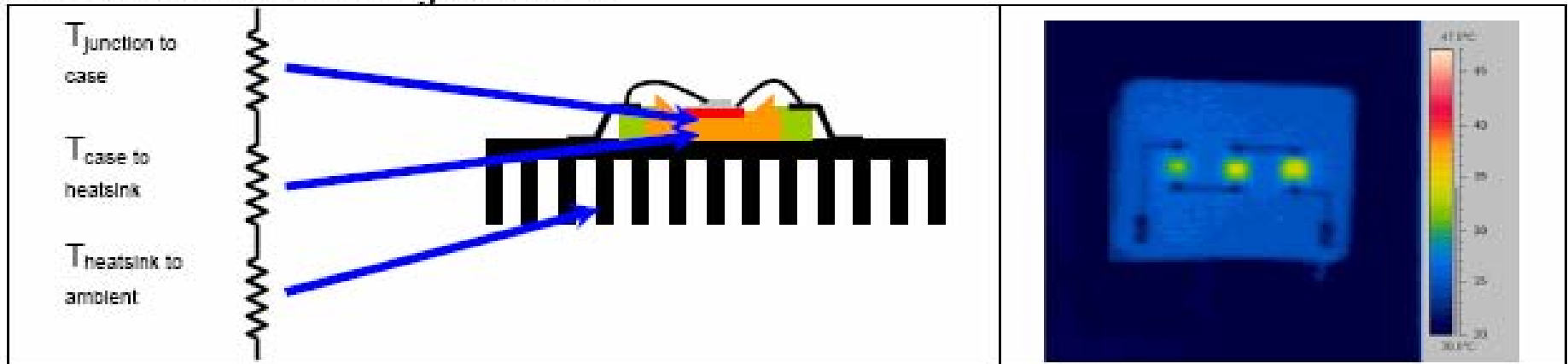
*Note 1. Optical and Electrical specifications are given for the specified drive current at a 25 $^{\circ}\text{C}$ junction temperature.

From Lamina ceramics

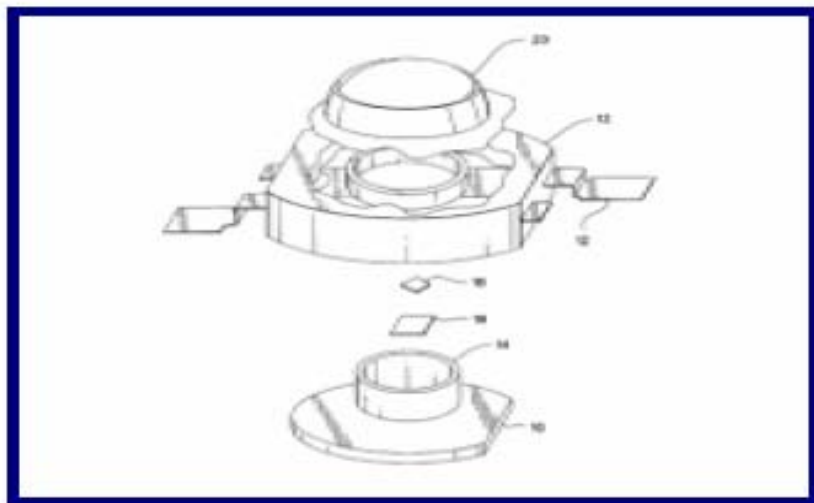
Thermal Characteristics using Metal Cored Substrate Technology



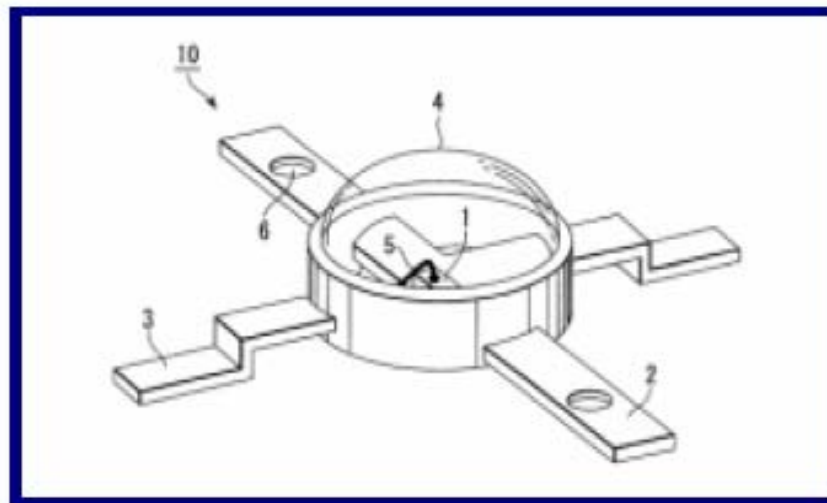
Thermal Characteristics using Anotherm[®]



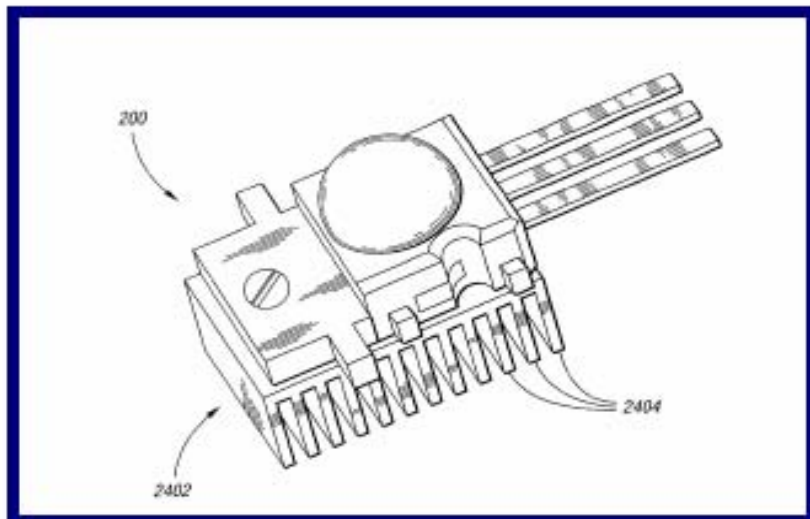
•Lumileds



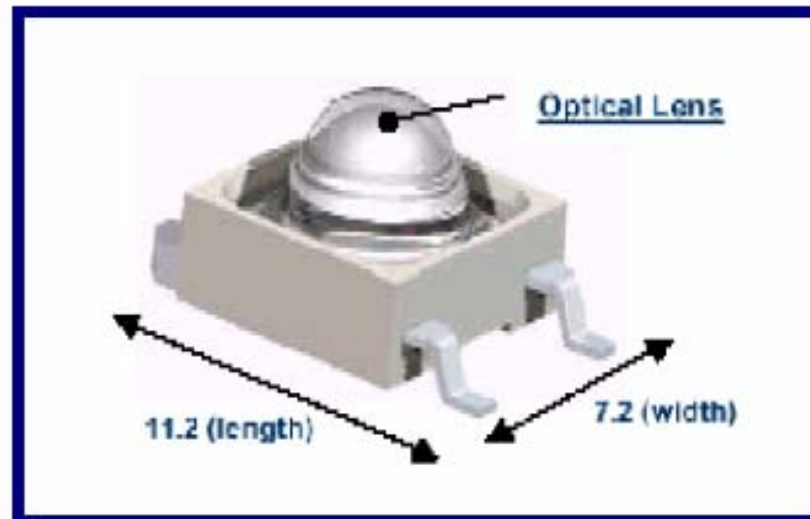
•Toshiba

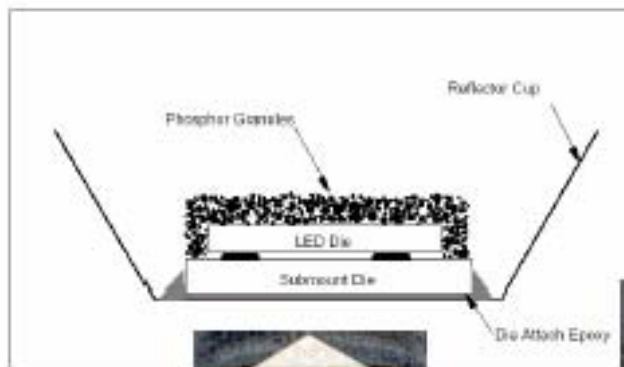
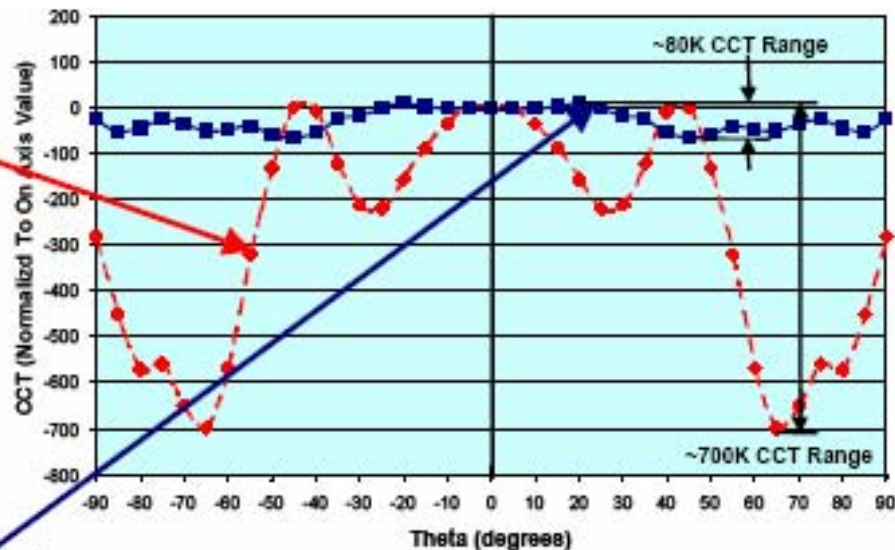
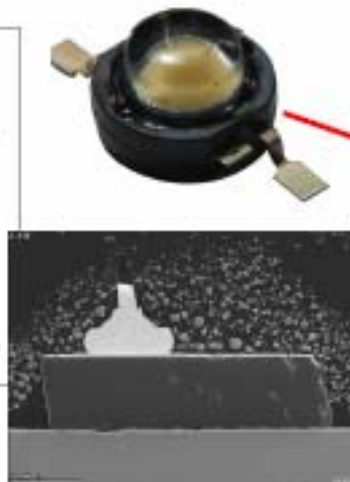
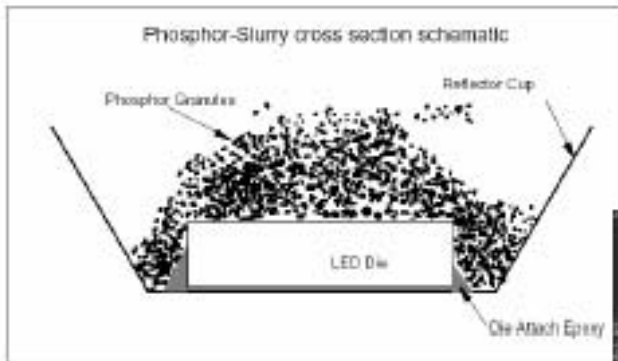


•Gentex



•Nichia





- Free standing white “chip”
- Smaller source size (étendue)
 - reduced dependence on viewing angle
 - higher lamp to lamp uniformity
- Flexible secondary optics design
- No reflector cup
 - Alternate radiation pattern
 - Compact lamp design

LUMILEDS

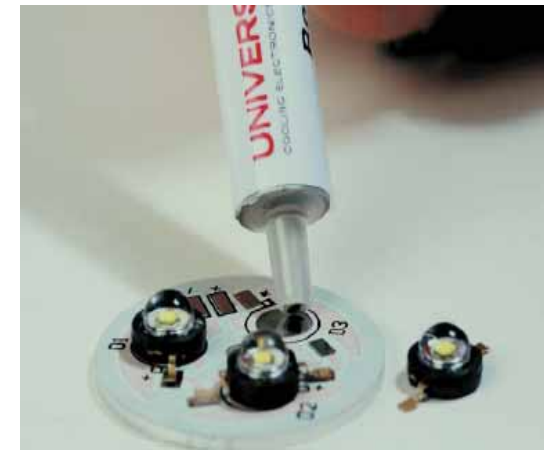


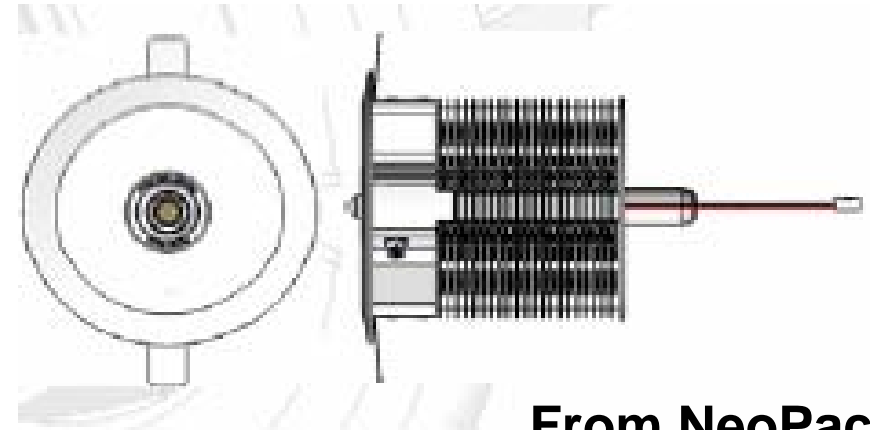
Cool white

- Typical flux : $>40 \text{ lm}$ (@ 350mA & $T_j 25^\circ\text{C}$)
- Maximum junction temperature: 135°C
- CRI > 70
- Thermal resistance: 13°C /W
- **Conformal phosphor coating**



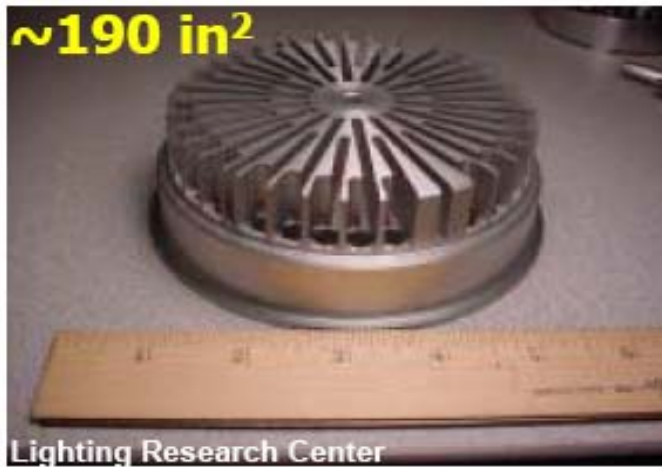
- Typical flux : $>70 \text{ Lumen}$ (@ 700mA & $T_j 25^\circ\text{C}$)
- Maximum junction temperature: 135°C
- CRI > 70
- Thermal resistance: 13°C /W
- Conformal phosphor coating
- SAE/ECE white color bins
- $>70 \text{ lm}$ available today @ 700 mA





From NeoPac

276lm @15.4W,18 lm/W



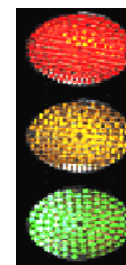
From PIER

Power Chip Market

40mil~
350mA~



14mil~24mil
20mA~100mA



12~14mil
5mA~20mA



Color LCD
White-light
conversion LED
backlighting

LED Keypad
White-light
conversion
LEDs behind
keys





LCD LED backlight

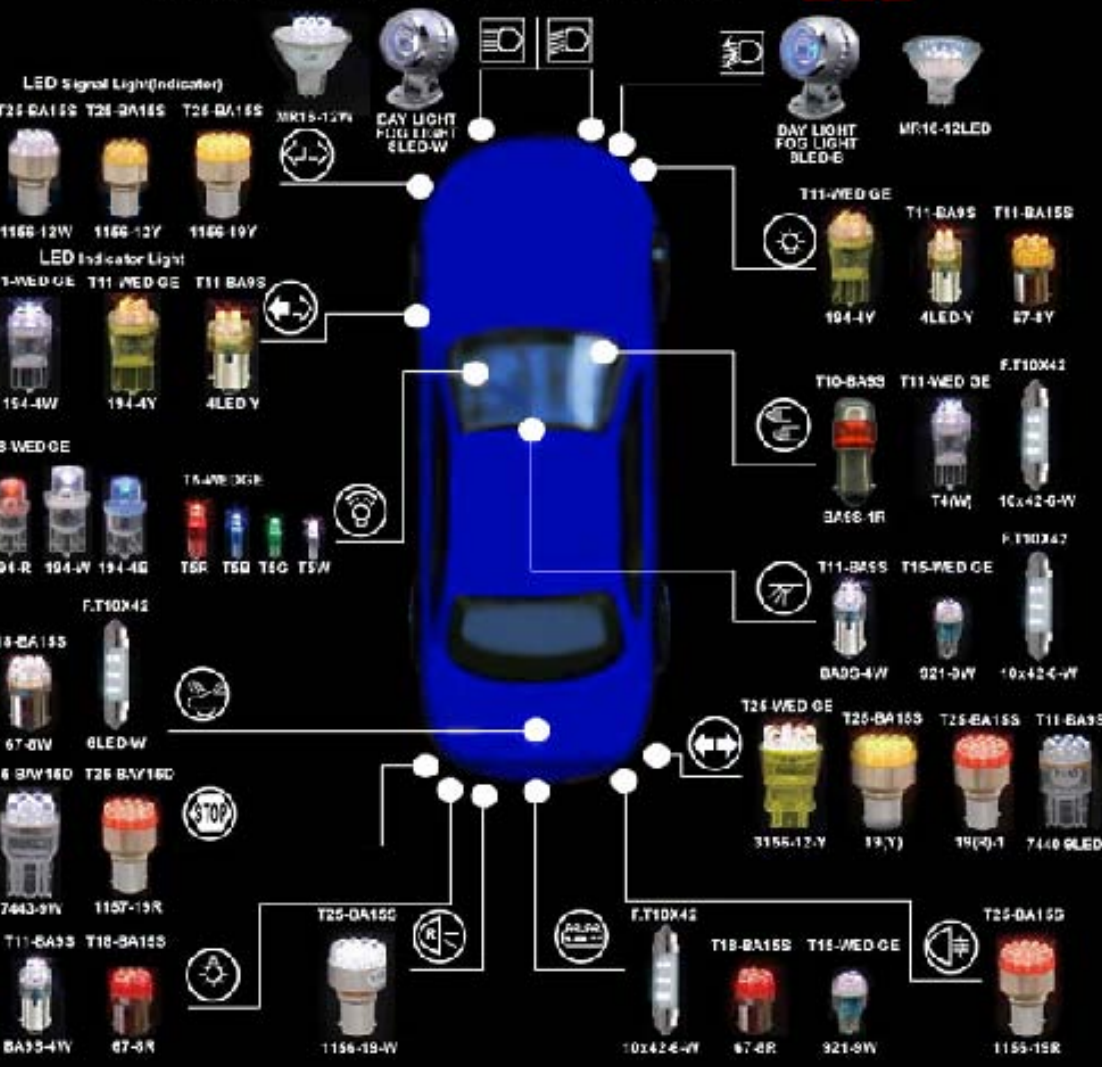


NEC 21'3 LED backlight



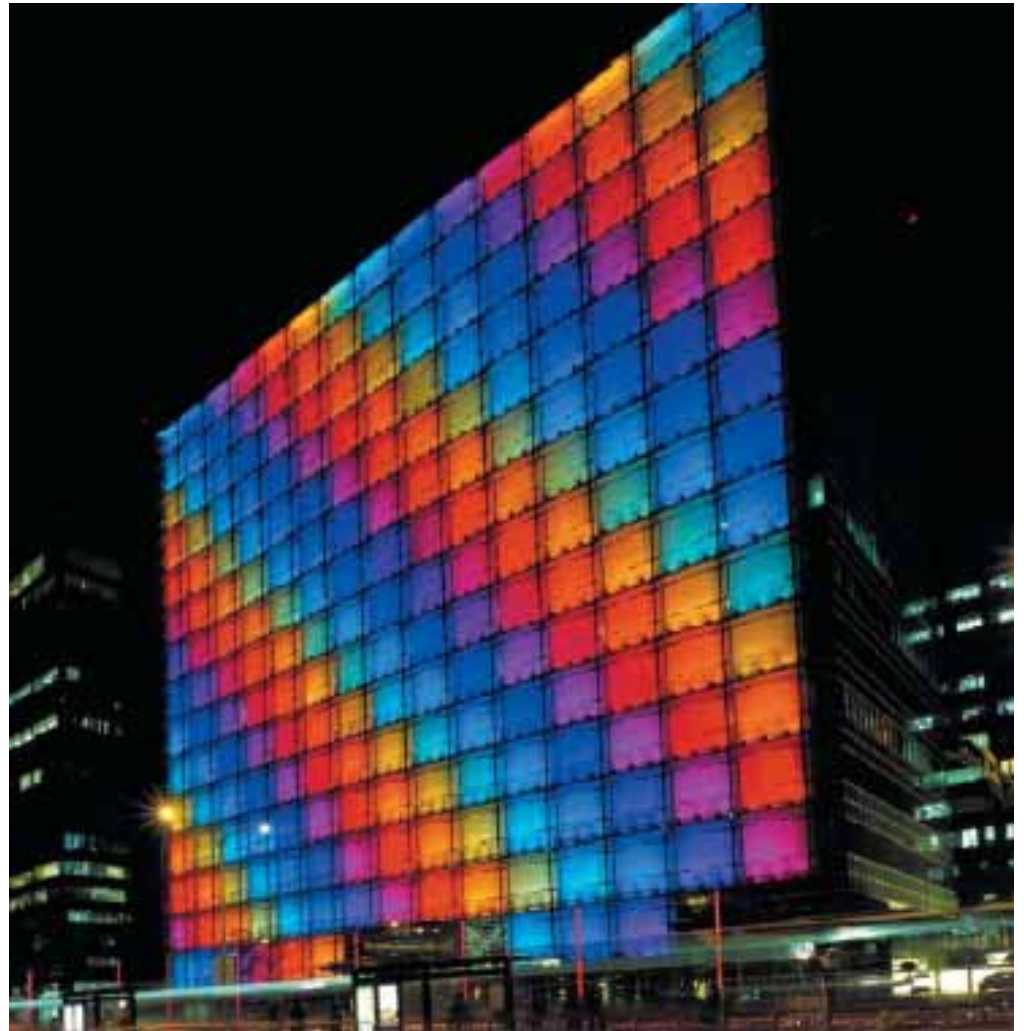
Sony 12'1 backlight

VARIOUS CAR USES SUPER BRIGHT LED



景觀燈

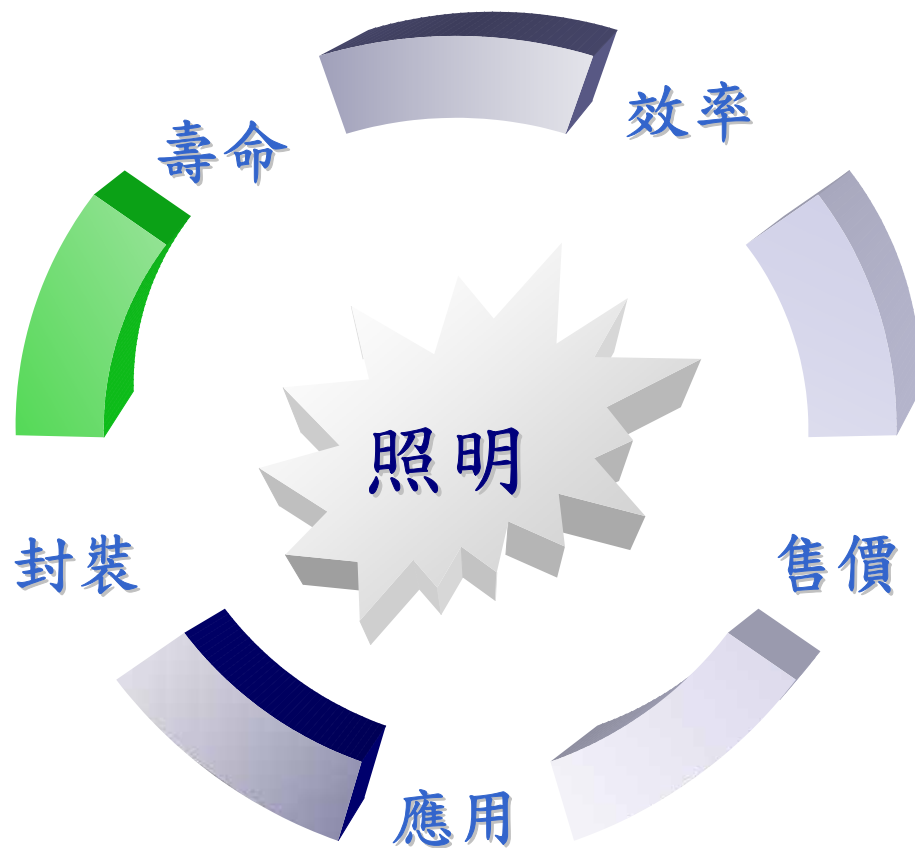




Taipei Municipal Social Education Hall



結論



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