Mechanical Engineering
National Central University

氮化鎵LED之電場模擬與電流擴散分析

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Excerpt from the Proceedings of the 2011 COMSOL Conference in Taipei

Background

- Illumination (lighting) consumption
  - ~20% of electricity
    (electricity ⇒ 40-60% of total energy)
  - ~8-10% of total energy

- Efficiencies of energy technological in building

Heating:	70-80%
Elecrical Motors:	85-95%
Lamp:	~5% (10-20 lm/W)
Fluorescent Lamp:	~25% (60-80 lm/W)

- Conventional lighting
  - Low efficiency

Lighting consumes and wastes a lot of energy

Traditional and Solid State Lighting

1. 傳統照明光源特性

發展成熟，價格便宜

發光效率低，及耗電高

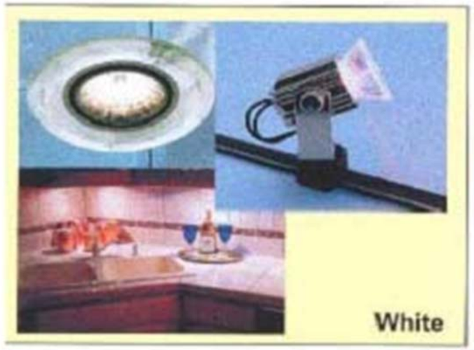
趨勢: 節約能源及環保意識

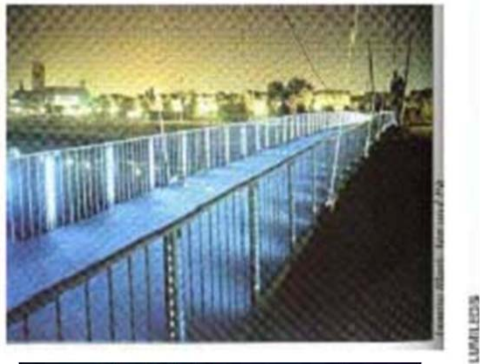
2. 白光LED固態照明光源特性

體積小(便利)，耗電量小(節能)

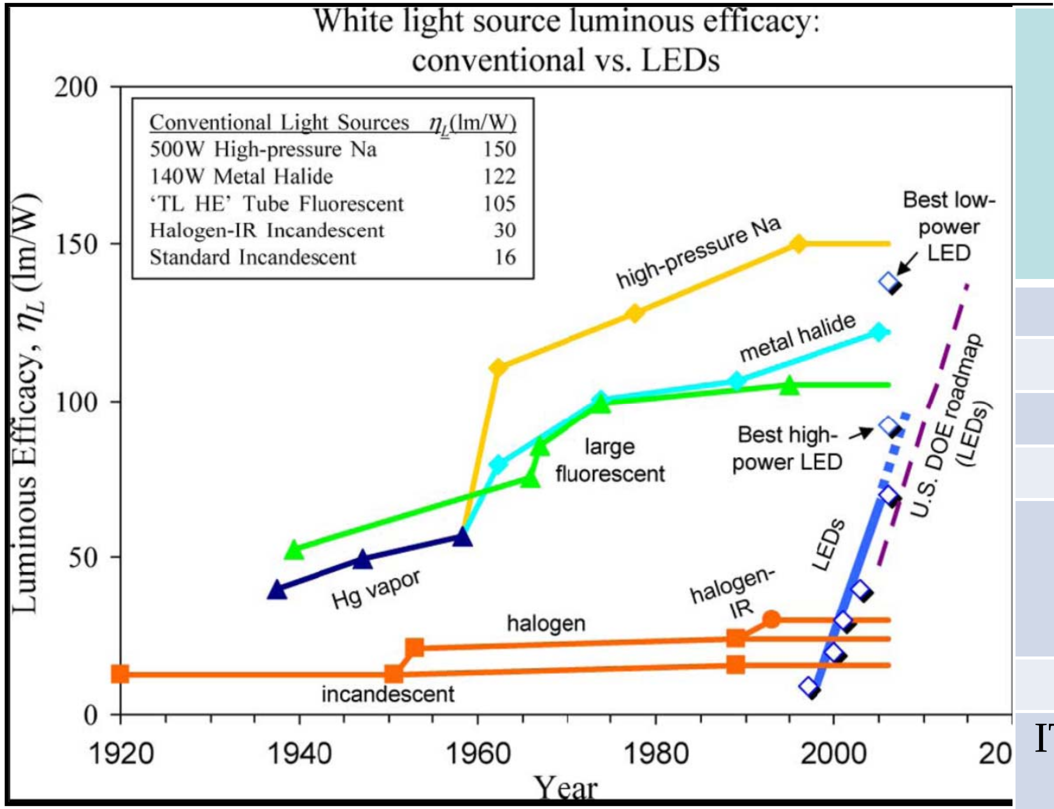
壽命長， 耐震，無汞，環保

色彩多樣性





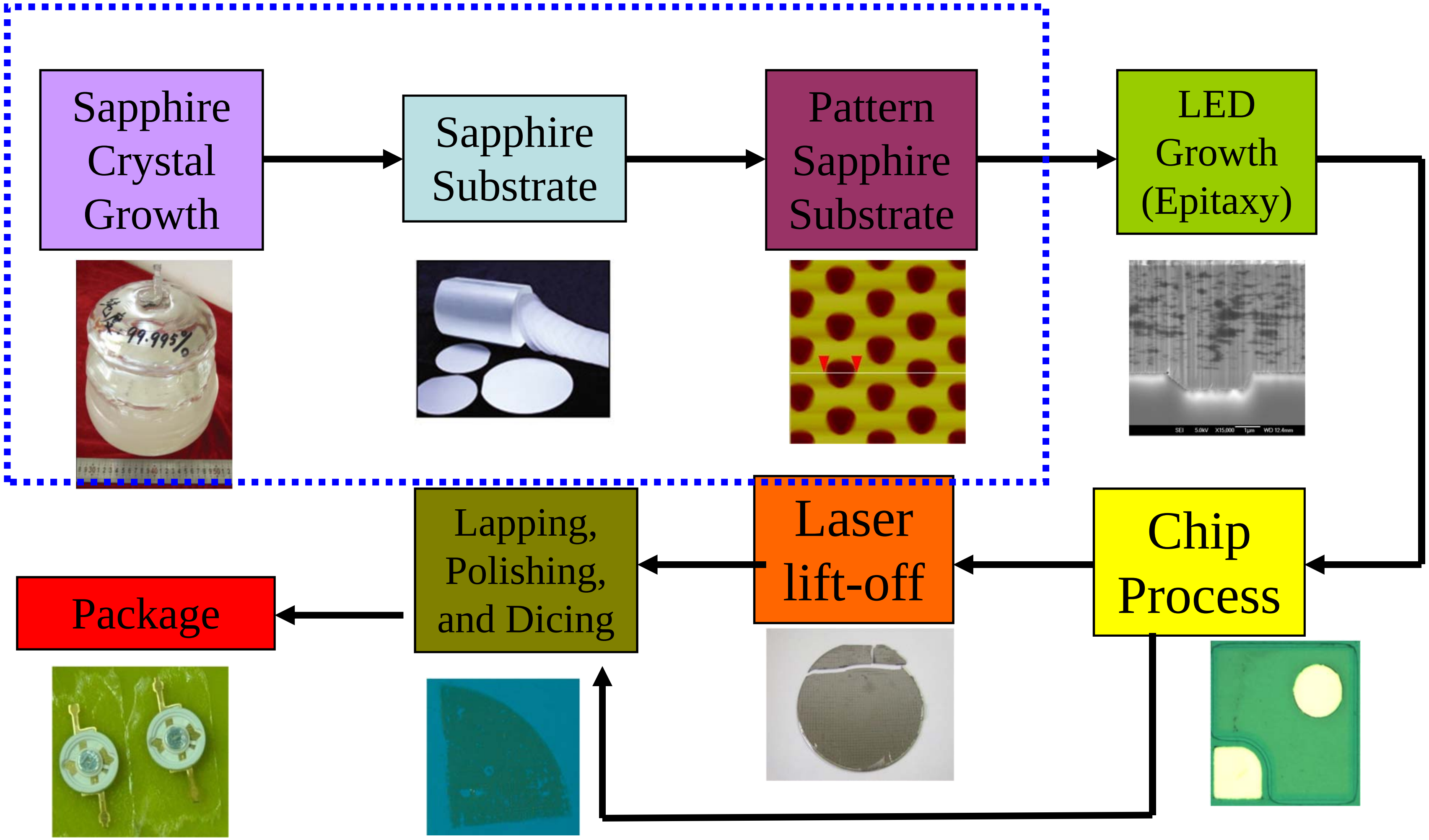
照明技術的發展



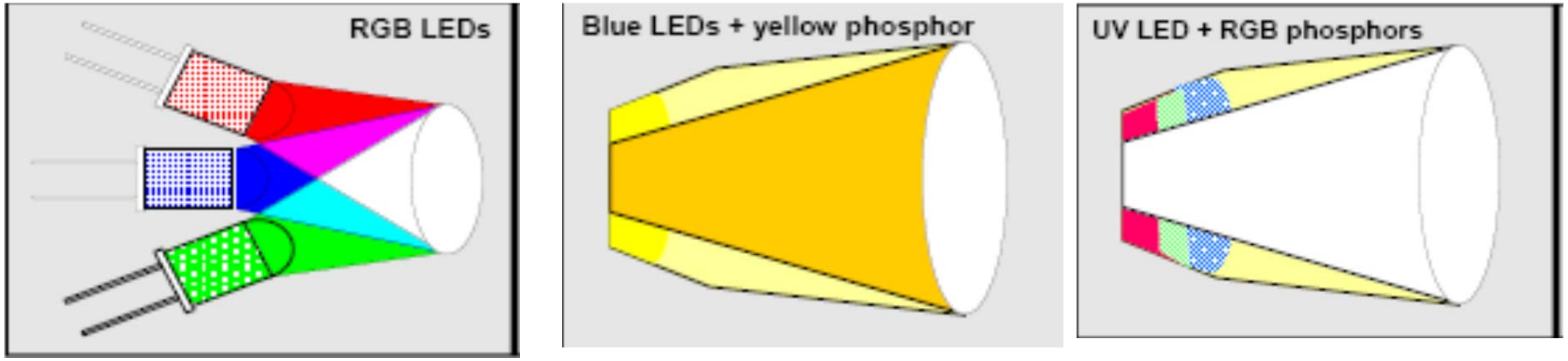
Krames *et al.* 2007

公司及機構	lm/W @ 大功率350 mA	
	Commercial Product	Laboratory
Cree	110	161
Lumileds	90	140
Nichia	100	145
Osram	100	136
Seoul semiconductor	100	n/a
Everlight	90	n/a
ITRI (AC LED)	n/a	50

Major Process Steps for LED Manufacturing



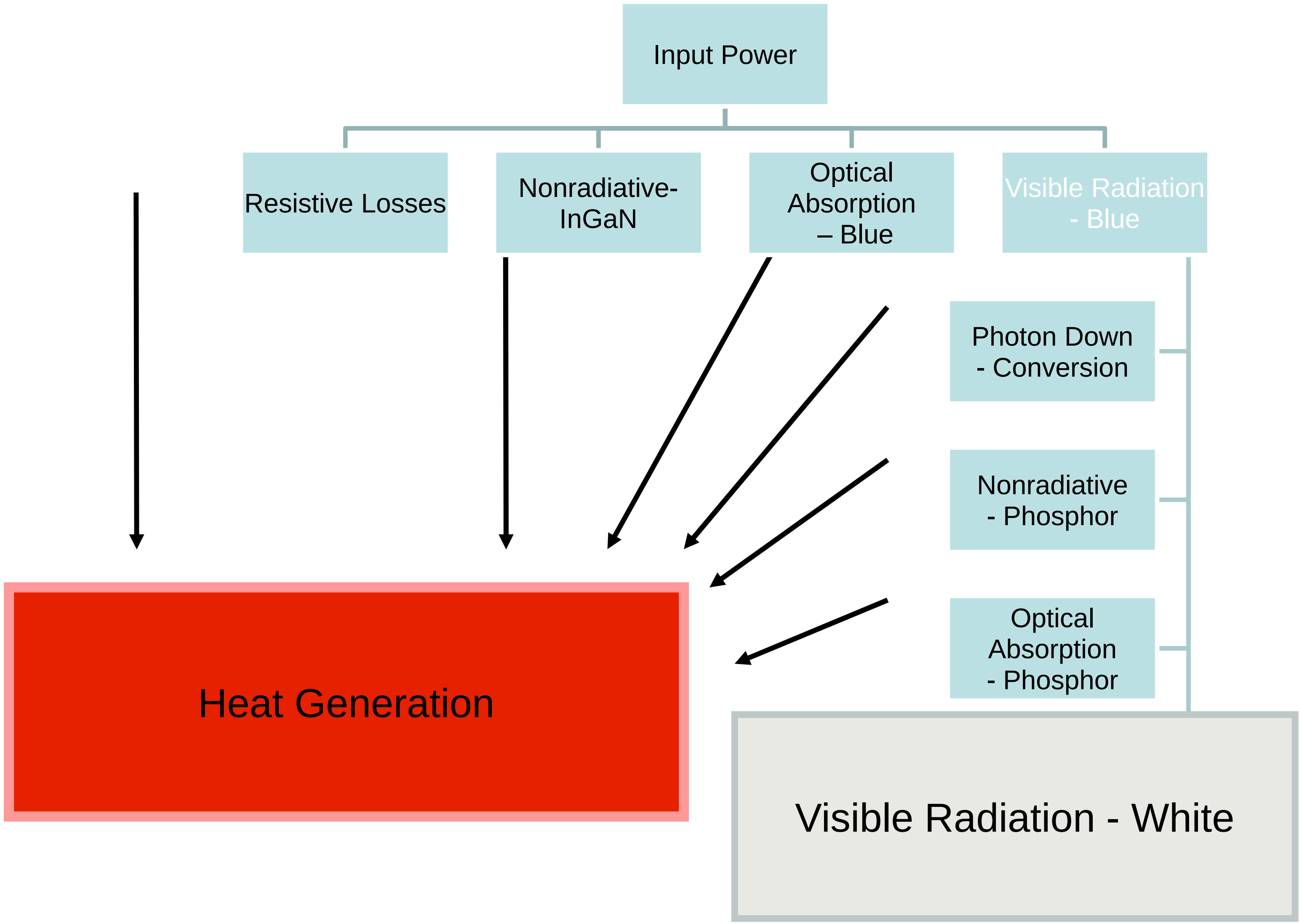
白光 LED 發光效率與能量效率之關係



	2002	2005	2007	2010	2012	2020
發光效率(Lm/w)	30	60	75	120	150	200
RGB 白光	10%	20%	25%	40%	50%	67%
藍光＋黃色螢光粉	12%	24%	30%	48%	60%	80%
UV＋三波長螢光粉	15%	30%	38%	60%	75%	100%

資料來源：www.Lumileds.com

LED之熱源(藍光＋黃色螢光粉)



能量轉換效率

- Commercially available high power LEDs (350 mW) at **70 lm/W**: **80% of power is lost to heat**, so only 20% goes to useful light output.

- Potential future performance -assuming internal quantum efficiency for the blue LED reaches 90% and modest reductions to electrical and optical losses—reaches **160 lm/W**. In this case, the power split between heat and light is approximately **50/50**.

	Resistive Losses	Nonradiative - InGaN	Optical Absorption - Blue	Visible Radiation - Blue	Photon Down - Conversion	Nonradiative - Phosphor	Optical Absorption - White	Visible Radiation - White
70 lm/W	19%	41%	6%	34%	7%	1%	5%	21%
160 lm/W	10%	9%	12%	69%	14%	3%	5%	47%

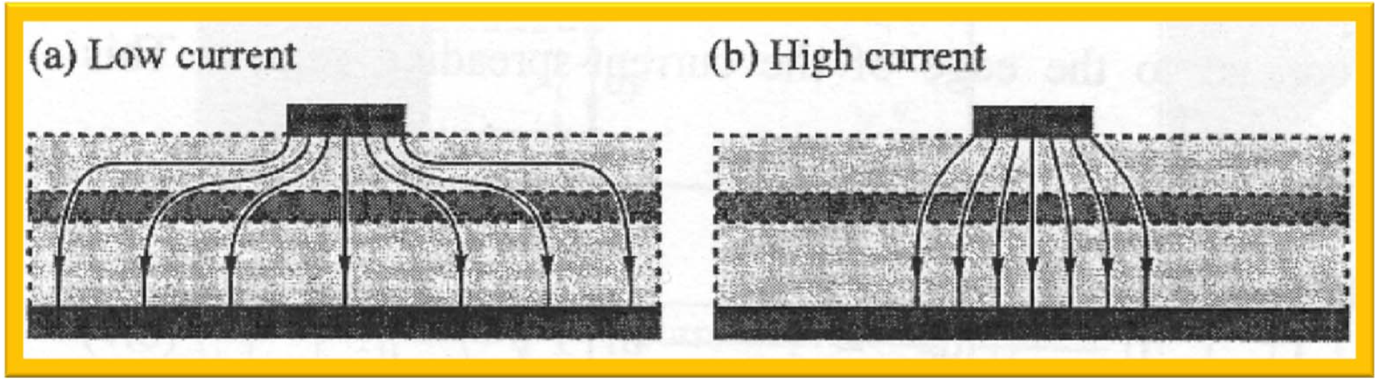
Krames *et al.* 2007

減少LED磊晶內熱產生之途徑

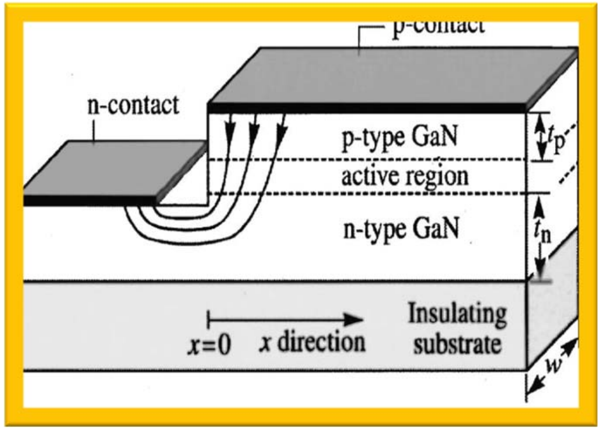
- 提昇LED內部量子效率，使輸入的電能大部分轉換成光輸出
- 提昇LED 的光取出效率，提高亮度，減少磊晶內光的吸收
- 經由電極或LED磊晶結構設計，均勻注入電流(Current Spreading) ，降低LED 之內電阻

電流壅塞現象

高電流注入下電流傳輸較差



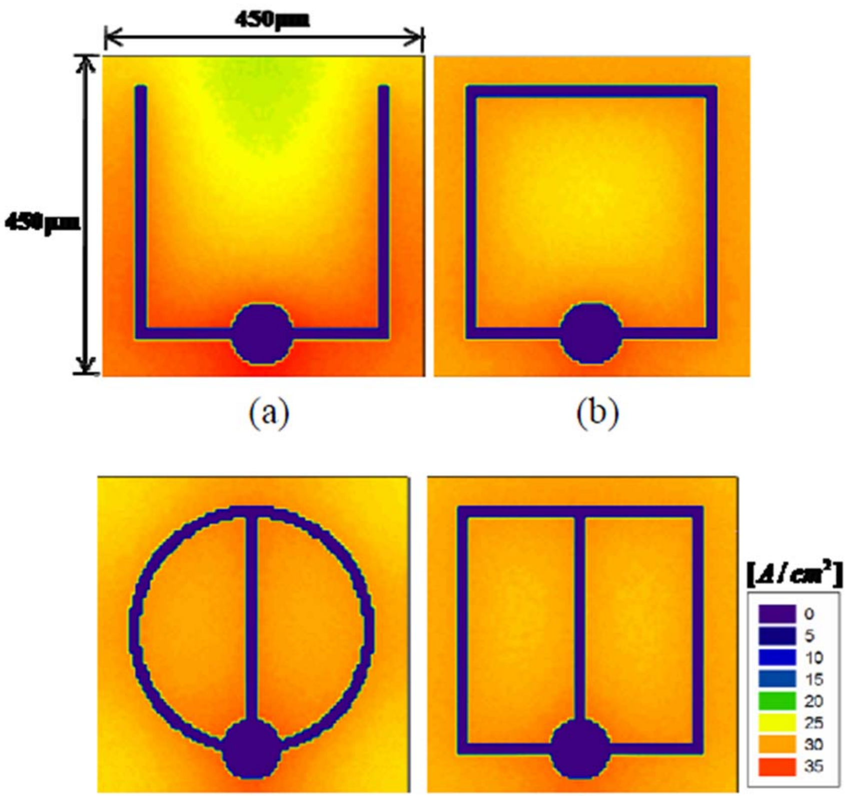
E. F. Schubert Light emitting diodes (2008)



大尺寸LED電極周圍會發生 Current crowding。

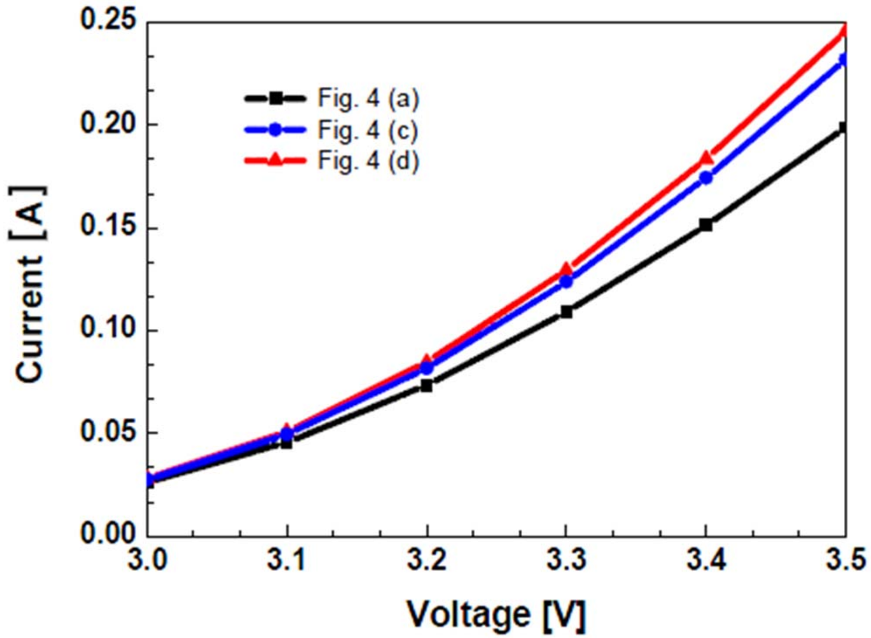
X. Guo and E. F. Schubert, J. of App. Phys. (2001)

電極設計之相關文獻



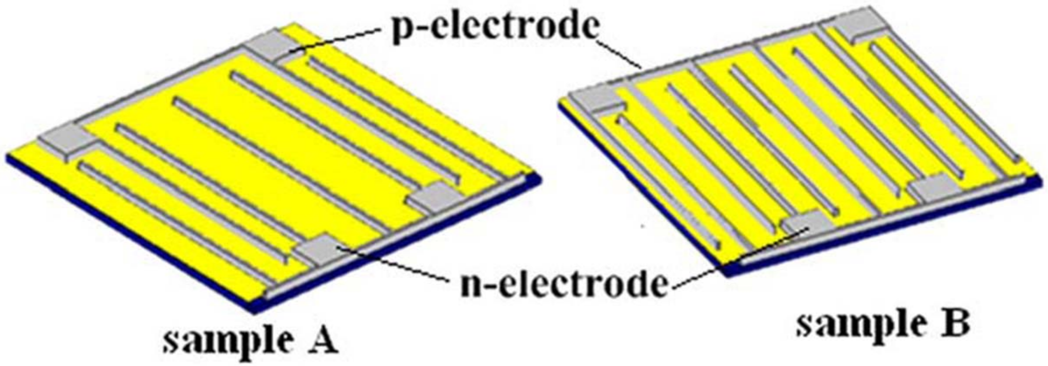
(a) (b)

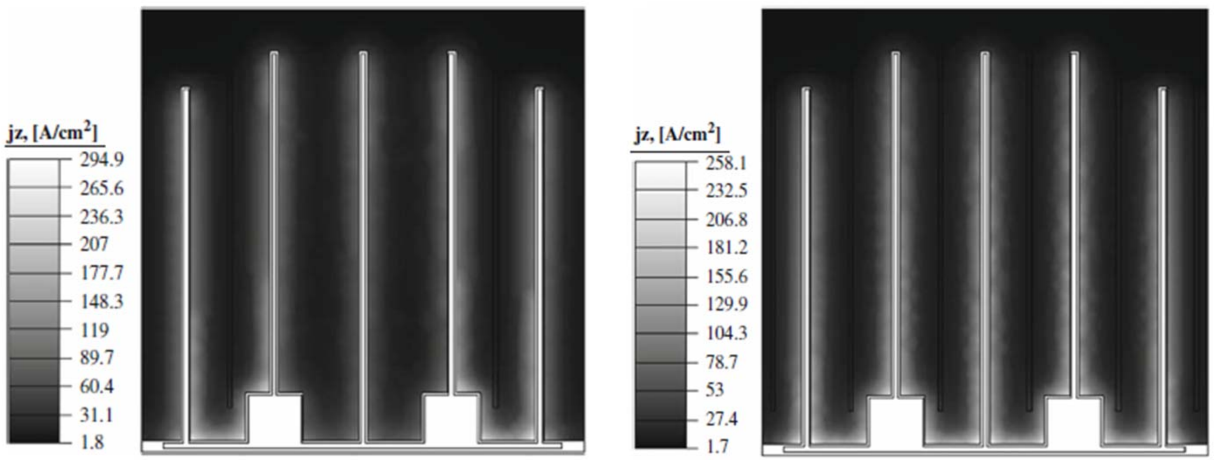
(c) (d)



J. S. Yun et al. *Proc. SPIE* (2007)

電極設計之相關文獻





$\Delta J\,(A/cm^2)$

$J_{max} - J_{min}$

Sample A	Sample B
293.1	256.4

P. Wang et al. *Opt. & Laser Tech.*(2010)

電場G.E. $$\frac{\partial[\nabla\cdot\varepsilon(\nabla\cdot V)]}{\partial t}+\nabla\cdot(\sigma\nabla V)=0$$

溫場G.E. $$\rho C_p\frac{\partial T}{\partial t}-\nabla\cdot(K\nabla T)=\dot{q}$$

產熱項分兩部分探討:(1)非發光層　　（電能直接轉為能熱→焦耳熱）

$$\dot{q}=J\cdot\nabla V \qquad (W/m^3)$$

（2）活化層　　（輸入電能-輸出光能）

$$\dot{q}=\frac{J_e}{l_e}\left[V_j-\frac{\hbar\omega}{e}\times EQE\times\exp\left(-\frac{T-300}{1600}\right)\right]$$

光子能量換算的電位勢

外部量子效率

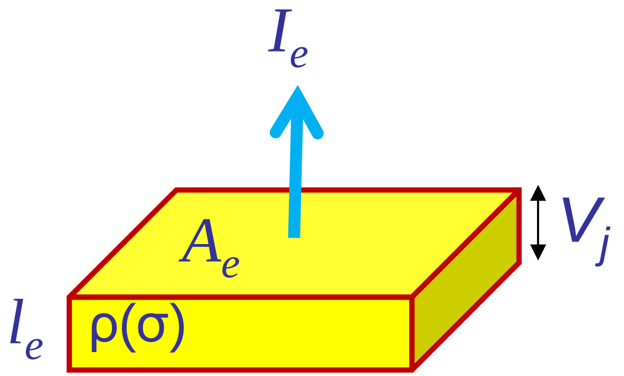
發光強度隨溫度升高而衰減

活化層之等效導電率假設

$$R = \frac{V_j}{I_e} = \frac{\rho \cdot l_e}{A_e} = \frac{l_e}{A_e \cdot \sigma}$$

$$\left\{ \begin{aligned} \sigma &= \frac{l_e \cdot I_e}{A_e \cdot V_j} = \frac{l_e}{V_j} \cdot J_e \\ J_e &= J_0 \left(\exp^{\frac{eV_j}{nkT}} - 1 \right) \end{aligned} \right.$$

$$\boxed{\sigma = \frac{l_e}{V_j} \cdot J_0 \left(\exp^{\frac{eV}{nkT}} - 1 \right)}$$

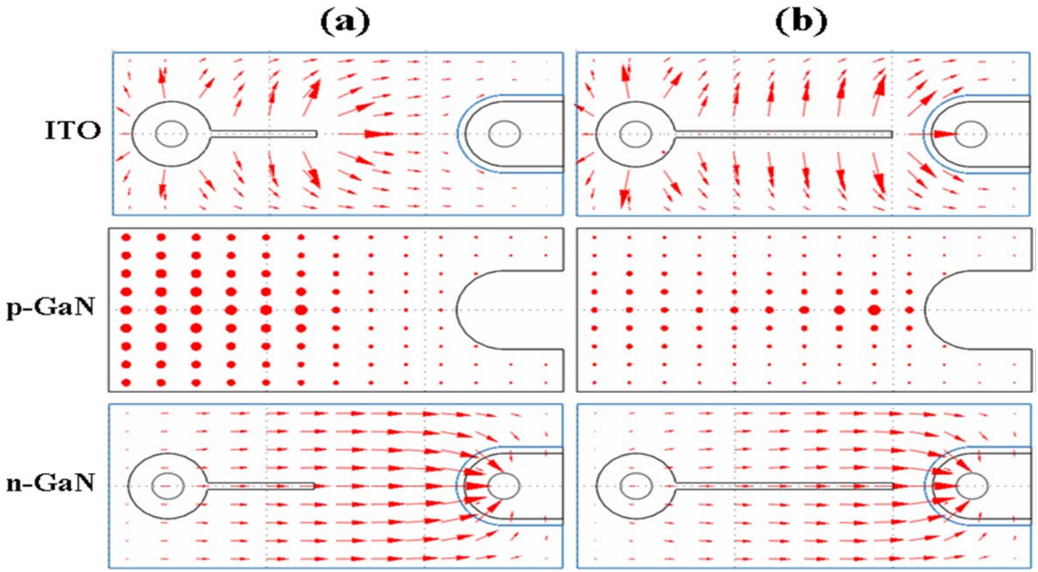


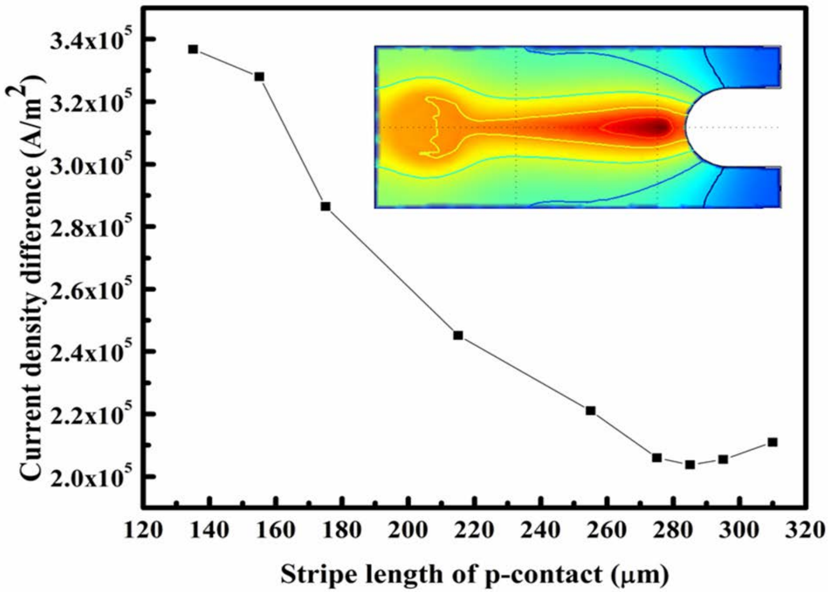
(Active layer Element)

★晶片溫度對飽和電流影響

$$J_0(T) = J_0\big|_{300K} \times 2^{(T-300)/10}$$

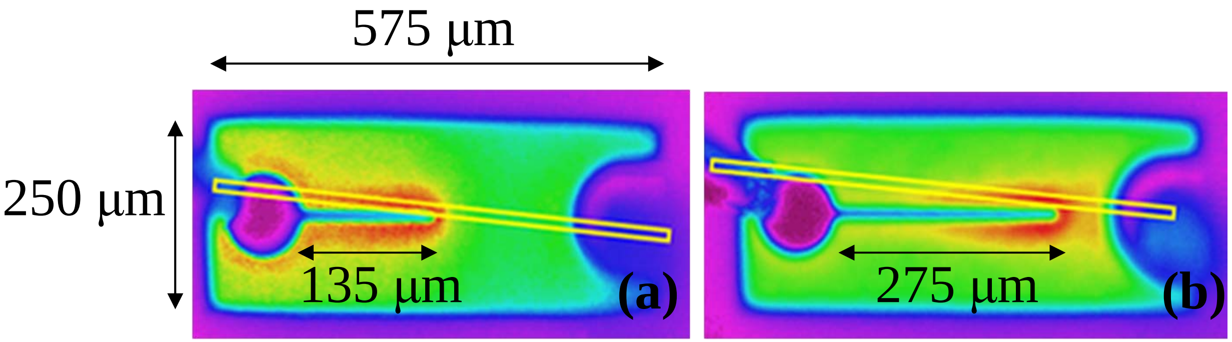
Side-View LED電場電流分佈分析



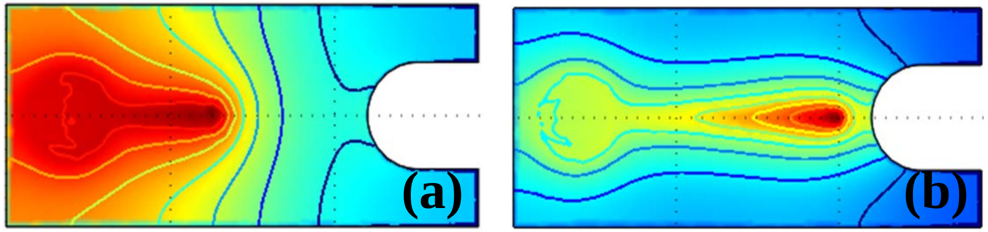


Current vectors in the top-view of the ITO, p-GaN, and n-GaN layers for: (a) the short case, and (b) the long case.

Relation between differences in current density and stripe length.

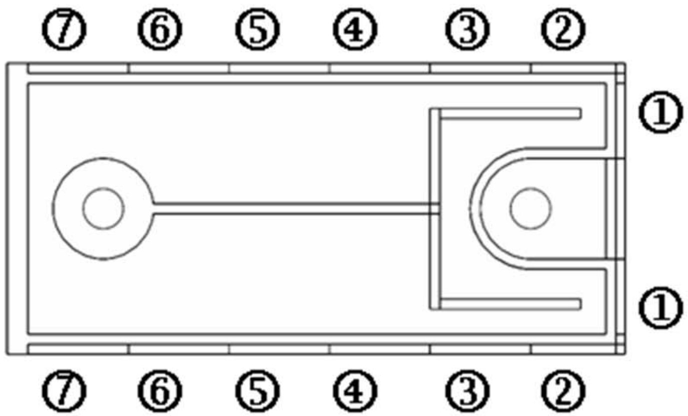


Micrographs of optical emissions operated at 30 mA for: (a) the short case, and (b) the long case.

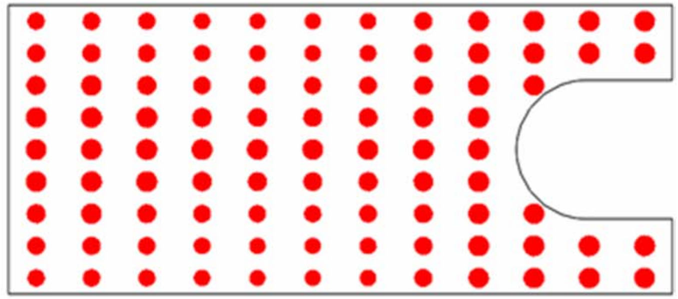


Isoline diagrams of simulated current densities for: (a) the short case, and (b) the long case.

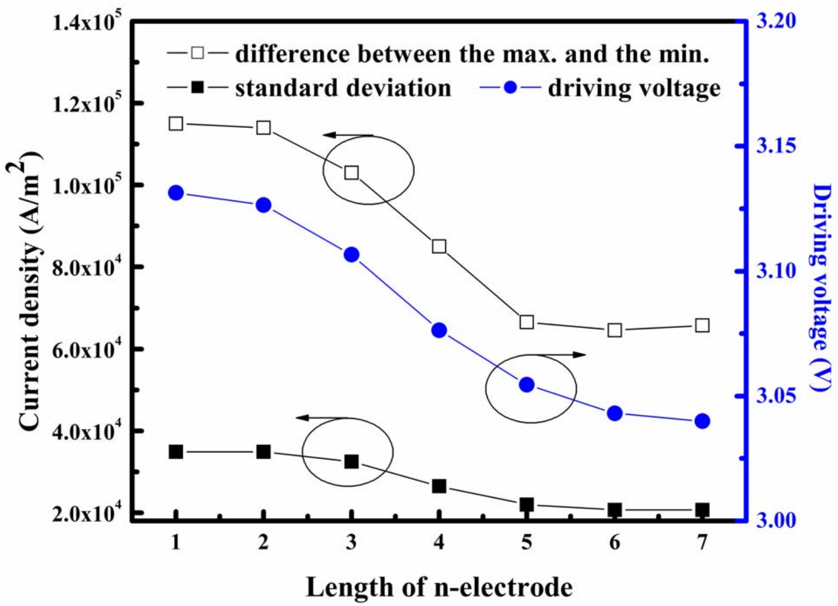
(a)



(b)



(C)



(a) Diagram of the p- and n-electrode patterns,

(b) 3D current arrows in the active layer for the no. 6 length n-electrode when operated at 30 mA.

(c) Relations of different n-electrode lengths with the current density in the active layer and driving voltage

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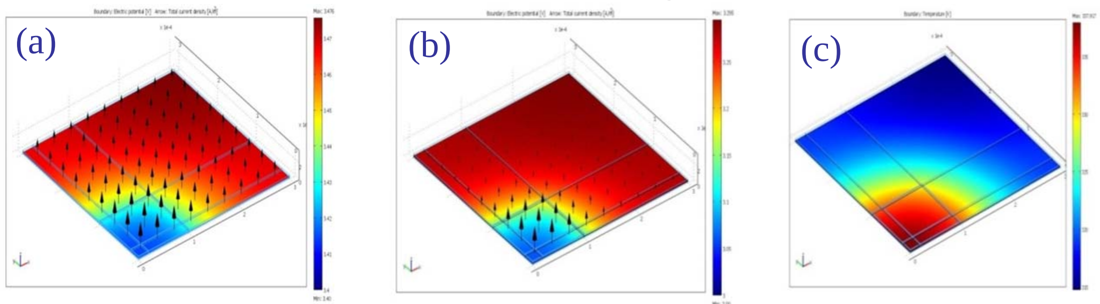
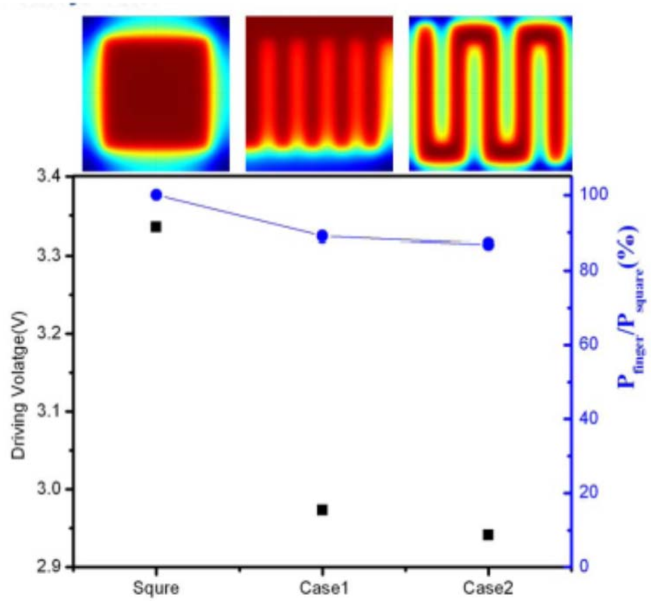
LED熱電耦合分析

–Electrical

Coupled Modeling of Current and Thermal Effects



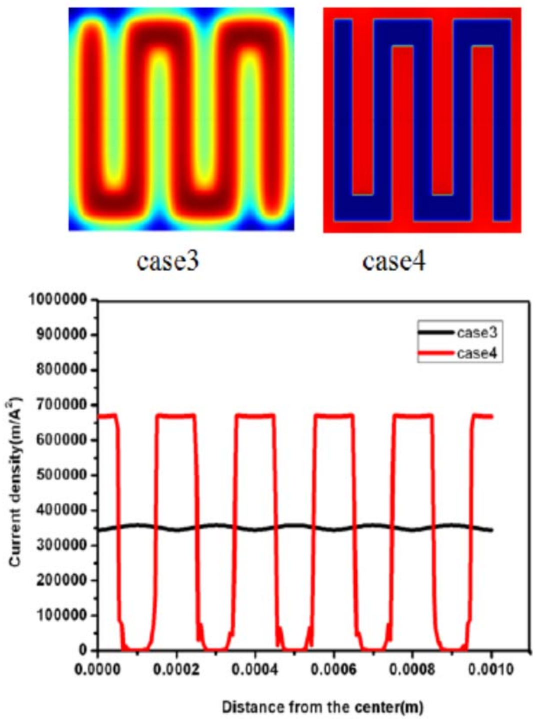
–Input current at100 mA: (a) distribution of voltage and current density at 300K , (b) distribution of voltage and current density with including the thermal dffect, (c) temperature distribution of case (b).



模擬VS實驗:8%

	Electrical model (NCU Simulation) Fig.(a)	Coupled model (NCU Simulation) Fig.(b) & (c)	2007, Kim, Korea (Experiment)
V_f (V)	4.097	3.816	3.8

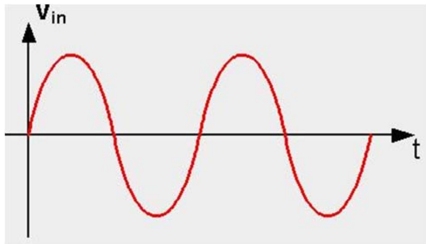
模擬VS實驗:1%

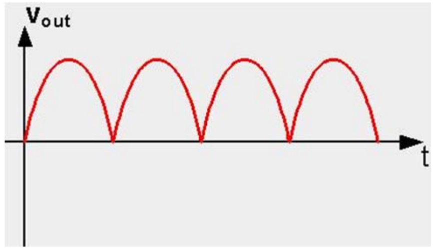


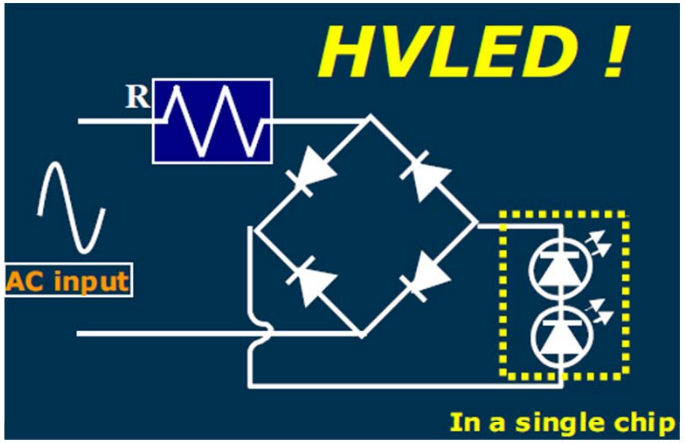
➢磊晶層的電特性會受到溫度影響改變，熱與電效應不停的交互影響。

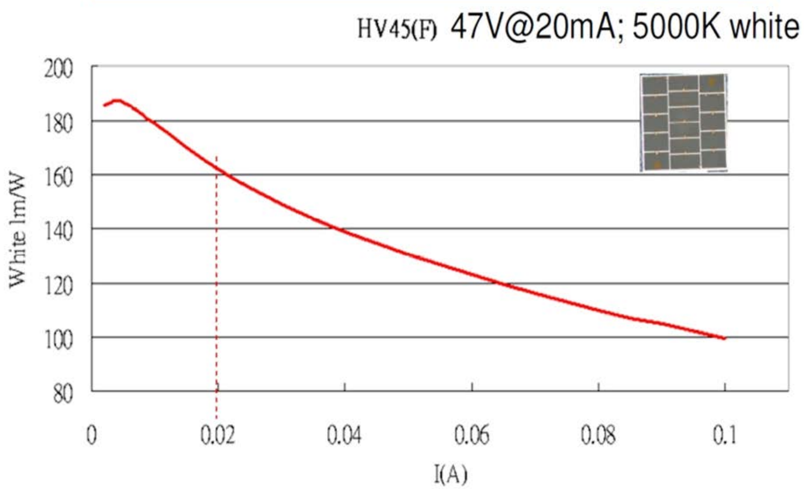
➢由新模型中發現crowding效應較大時，熱效應強化電流分佈的不均勻性。

高電壓LED (High Voltage LED)





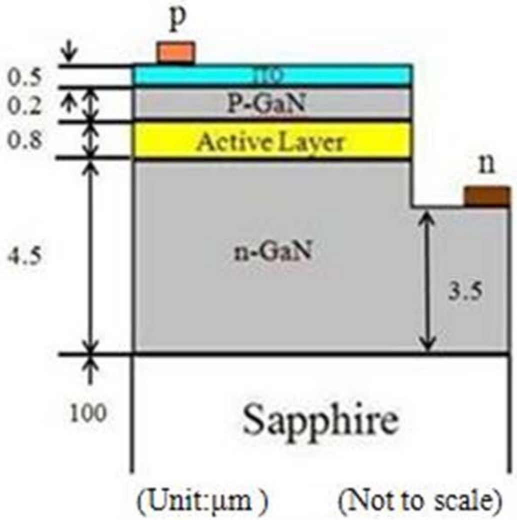




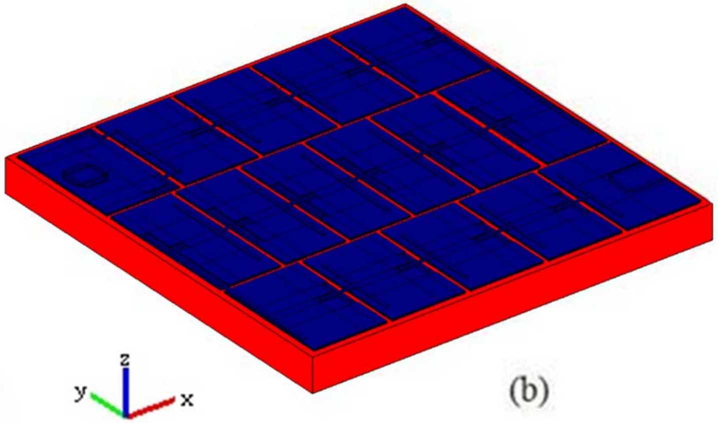
- 皆為串聯，可在更高的電壓下操作
- 操作彈性，AC & DC 皆可驅動
- The area ratio 100 %
- 20mA下，將可達到 **162 lm/W**

http://www.digitimes.com.tw/tw/B2B/Seminar/Service/download/0519910050/991005DTF-04.pdf
Epistar **(2010)**

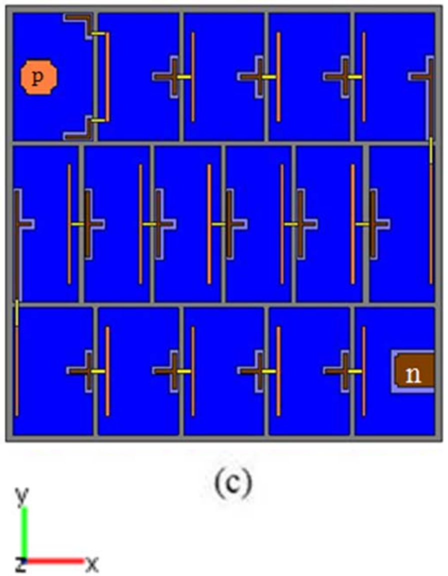
HV-LED物理模型



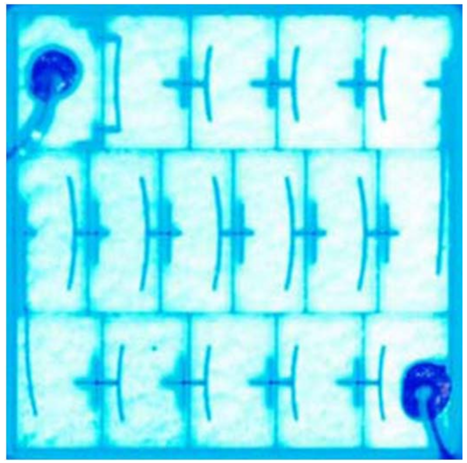
(a)



(b)

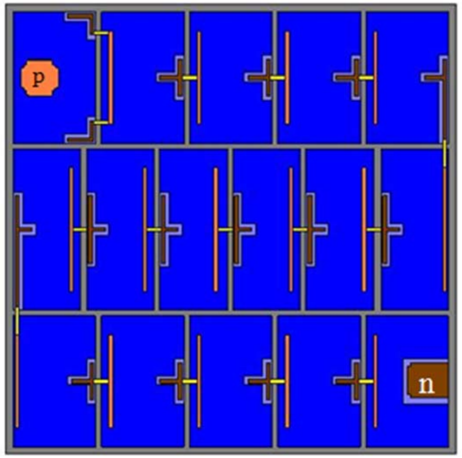


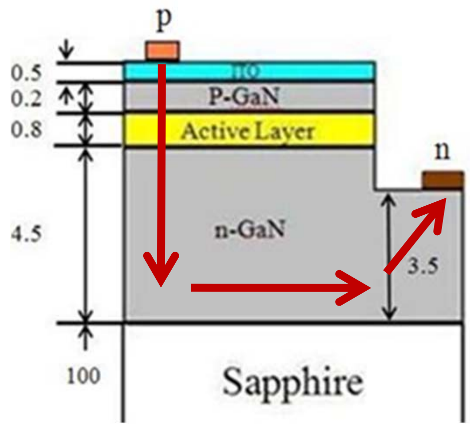
(c)

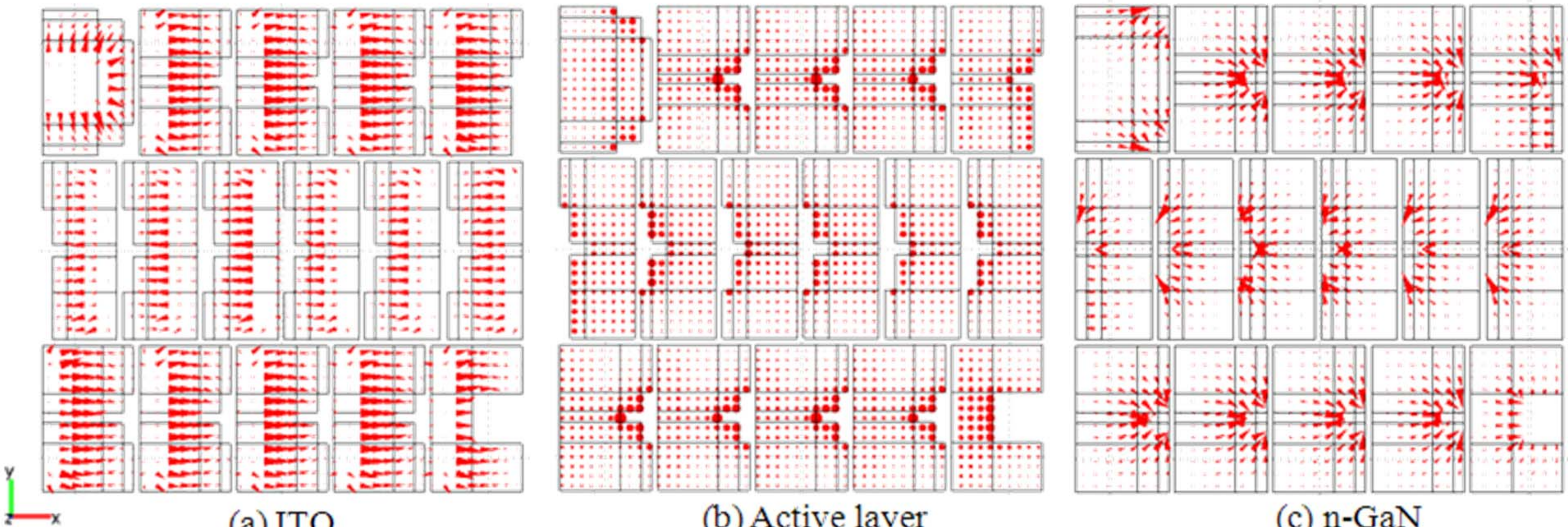


Electroluminescent driven by a 43 V forward voltage

HV LED 以DC 43.8V驅動之電流密度分佈

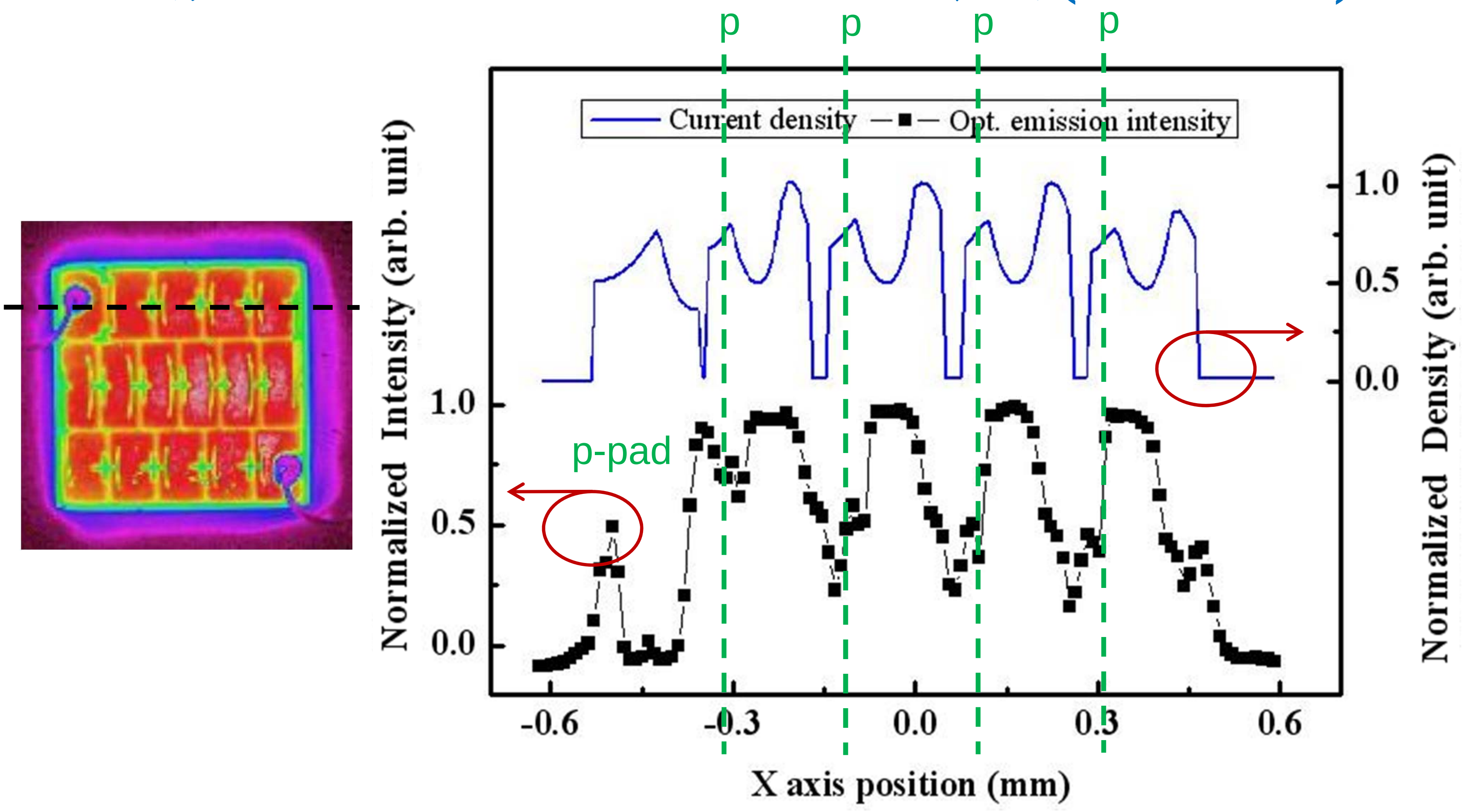




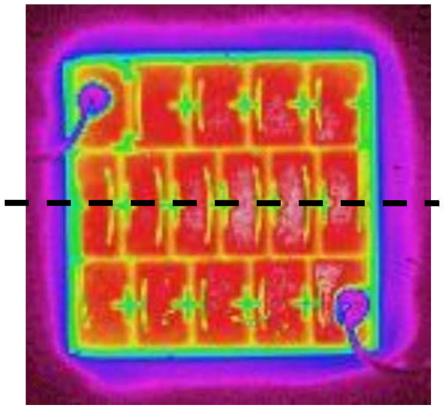


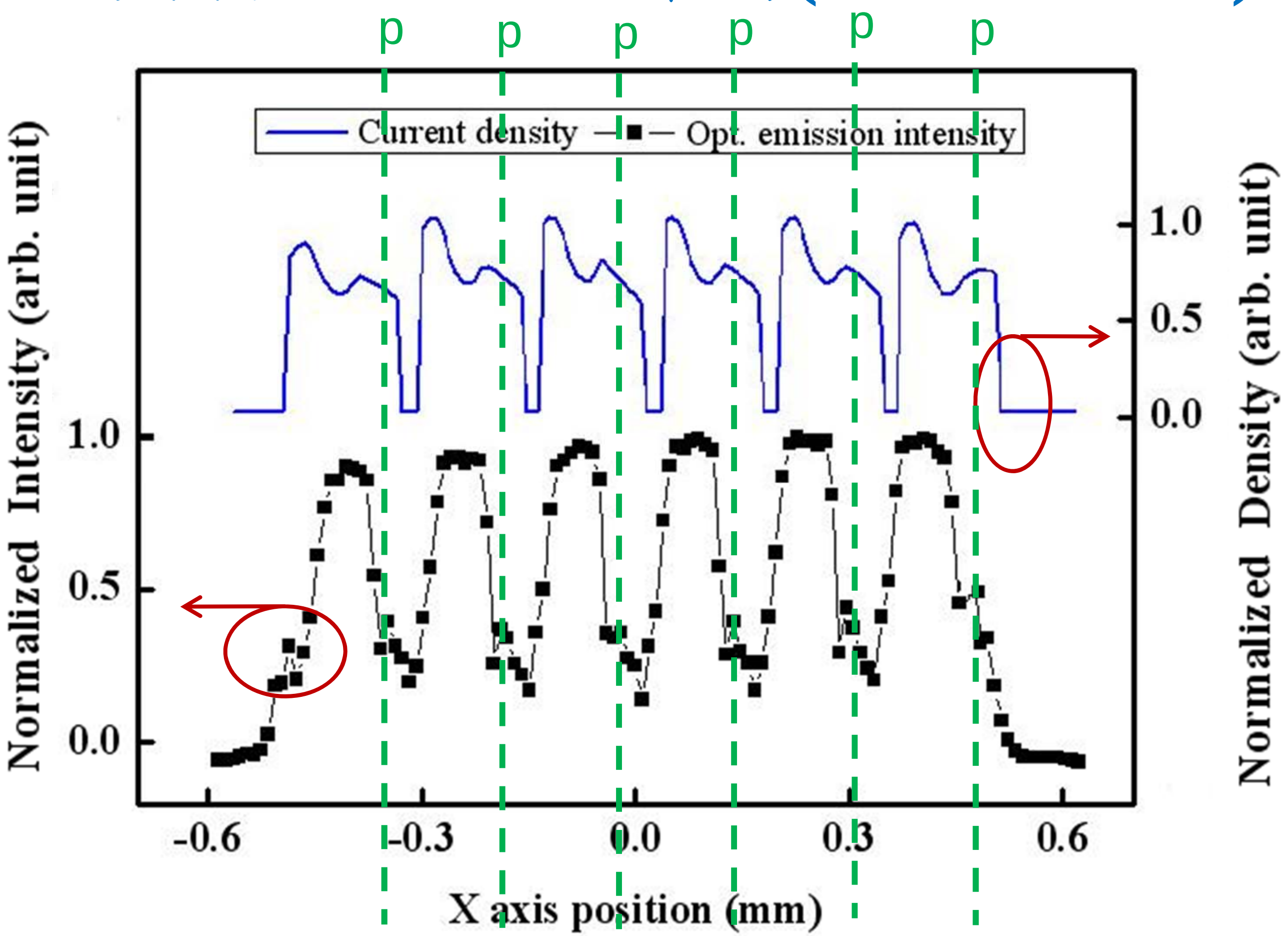
(a) ITO (b) Active layer (c) n-GaN

活化層電流密度與發光強度分佈圖(first row)



活化層電流密度與發光強度分佈圖(middle row)





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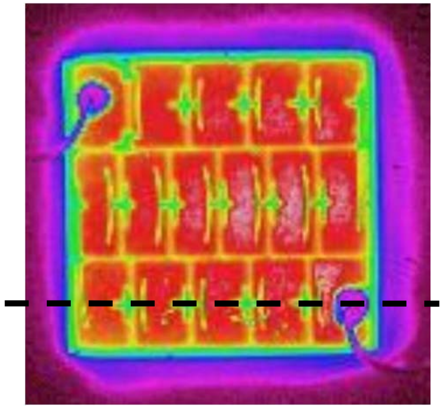
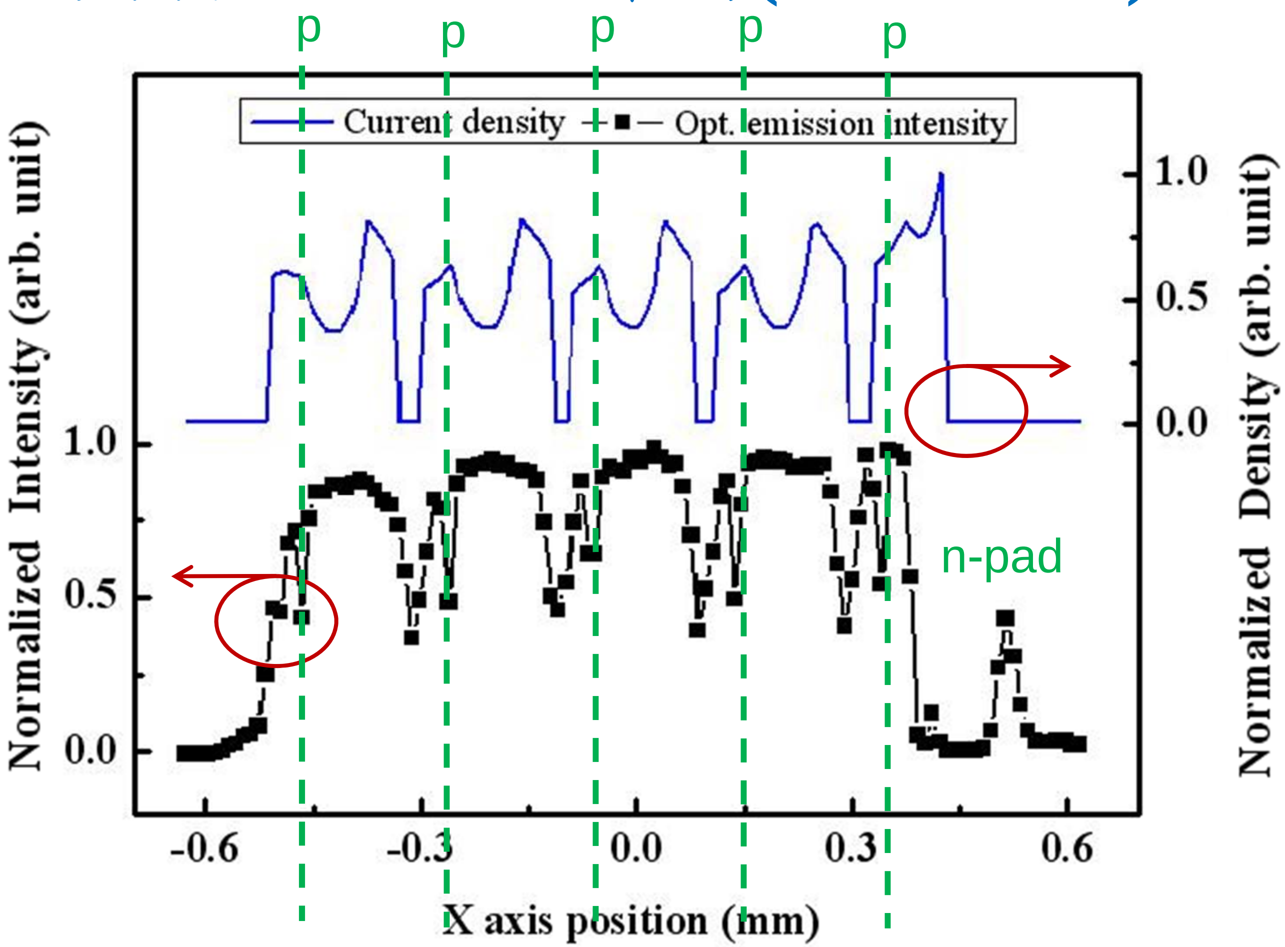
活化層電流密度與發光強度分佈圖(third row)





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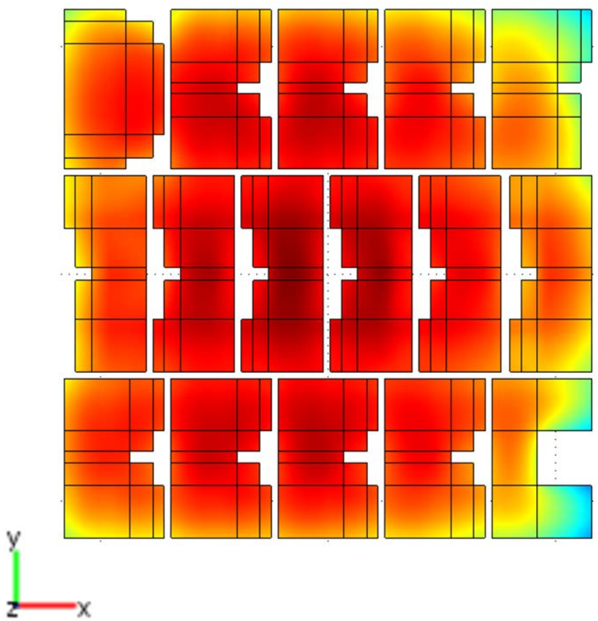
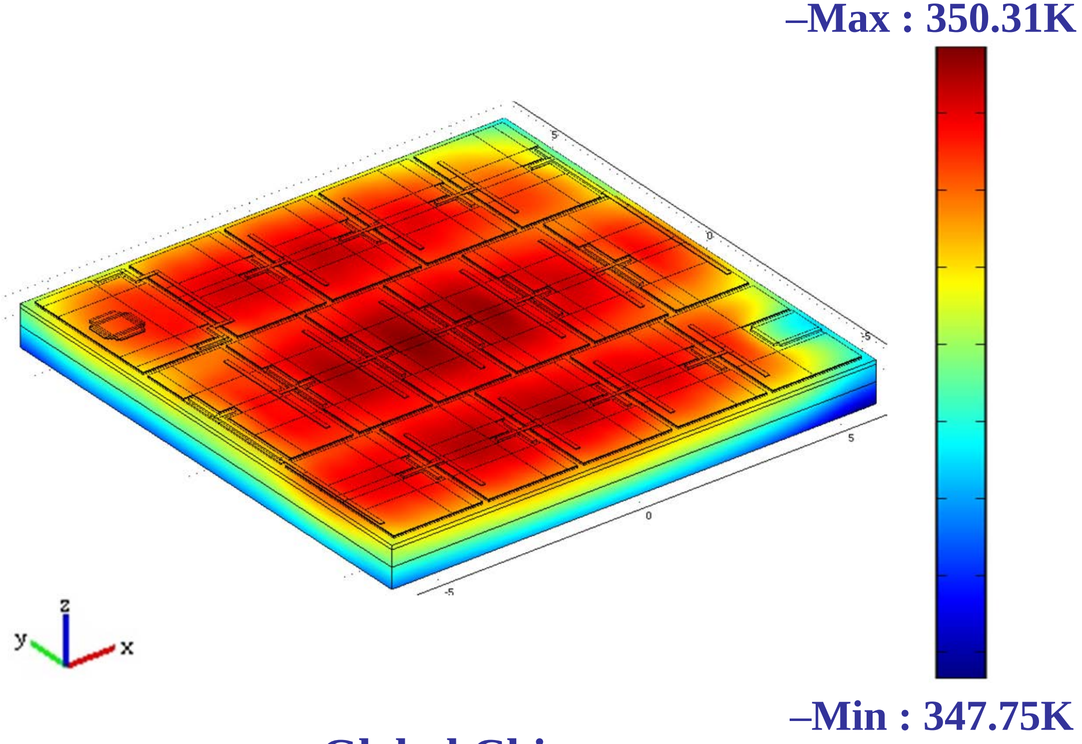
DC 43.8 V操作下之溫度分布



Active Layer



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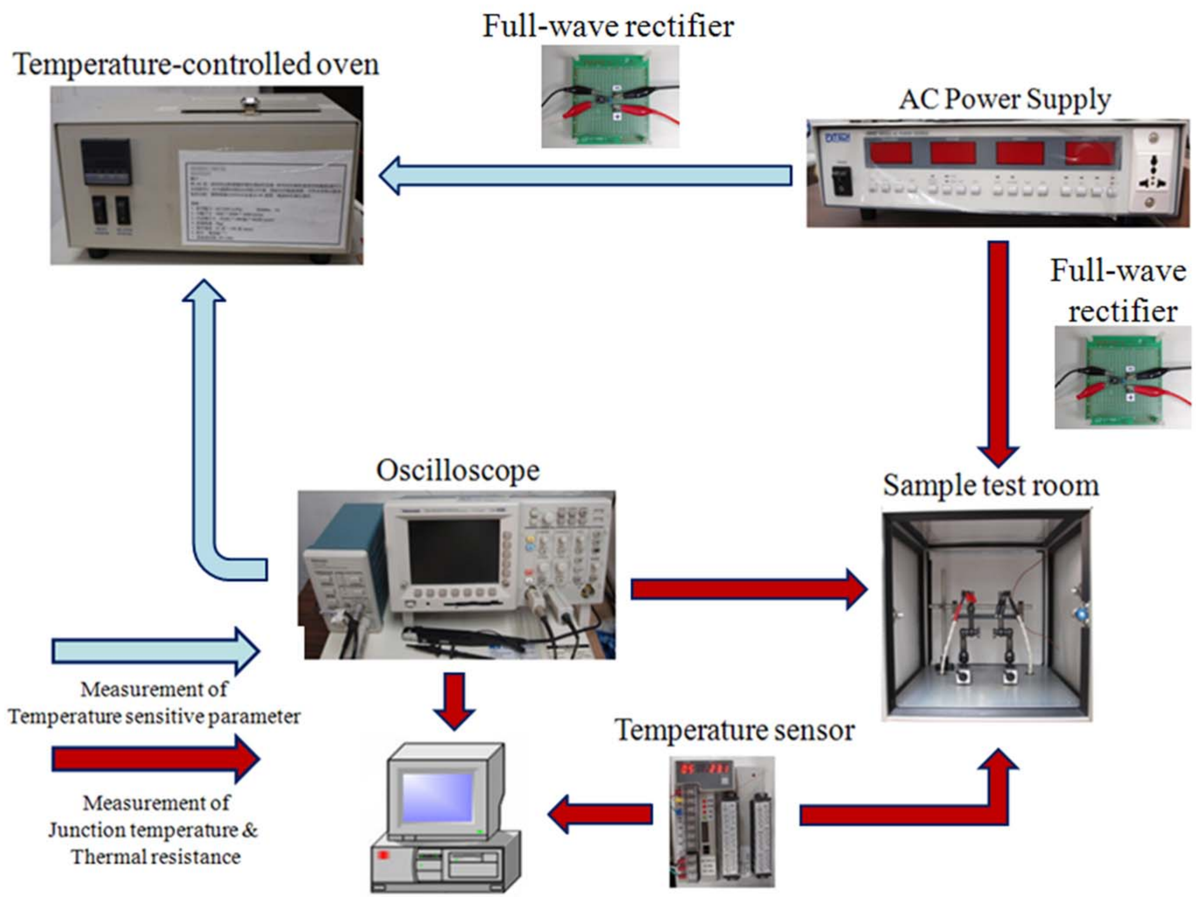
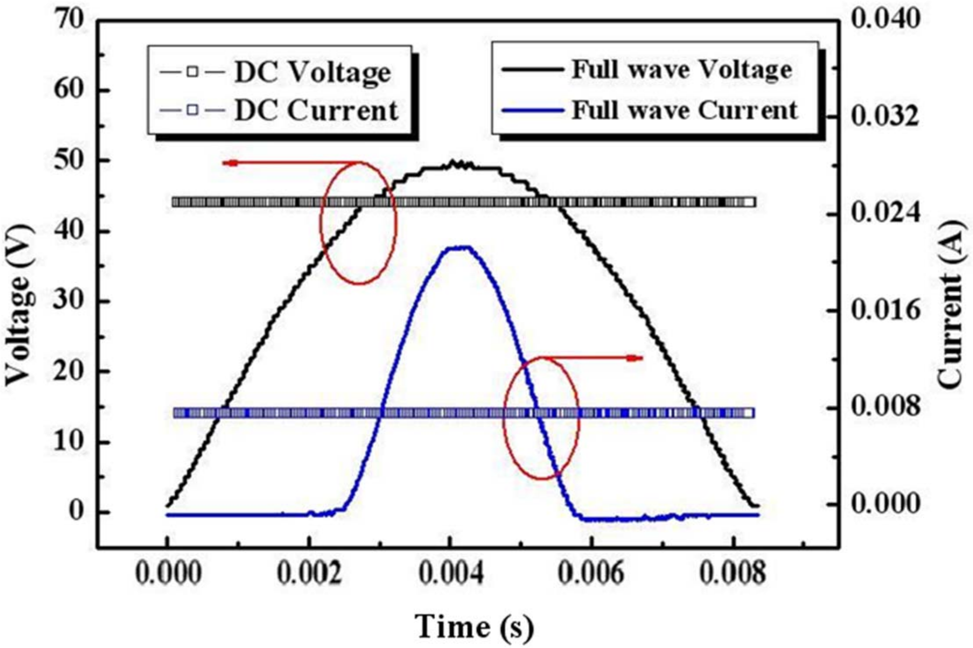
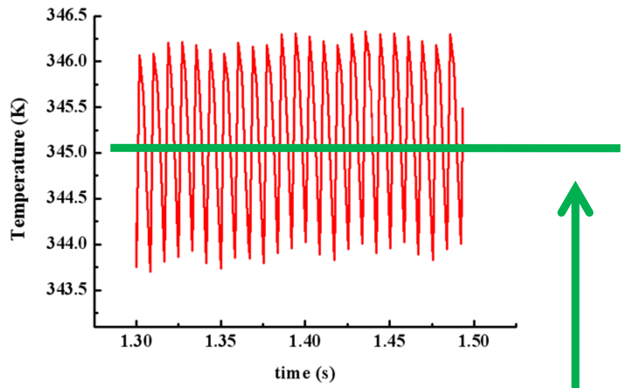
System for measuring the junction temperature of an HV LED



定功率下直流及全波輸入之接面溫度

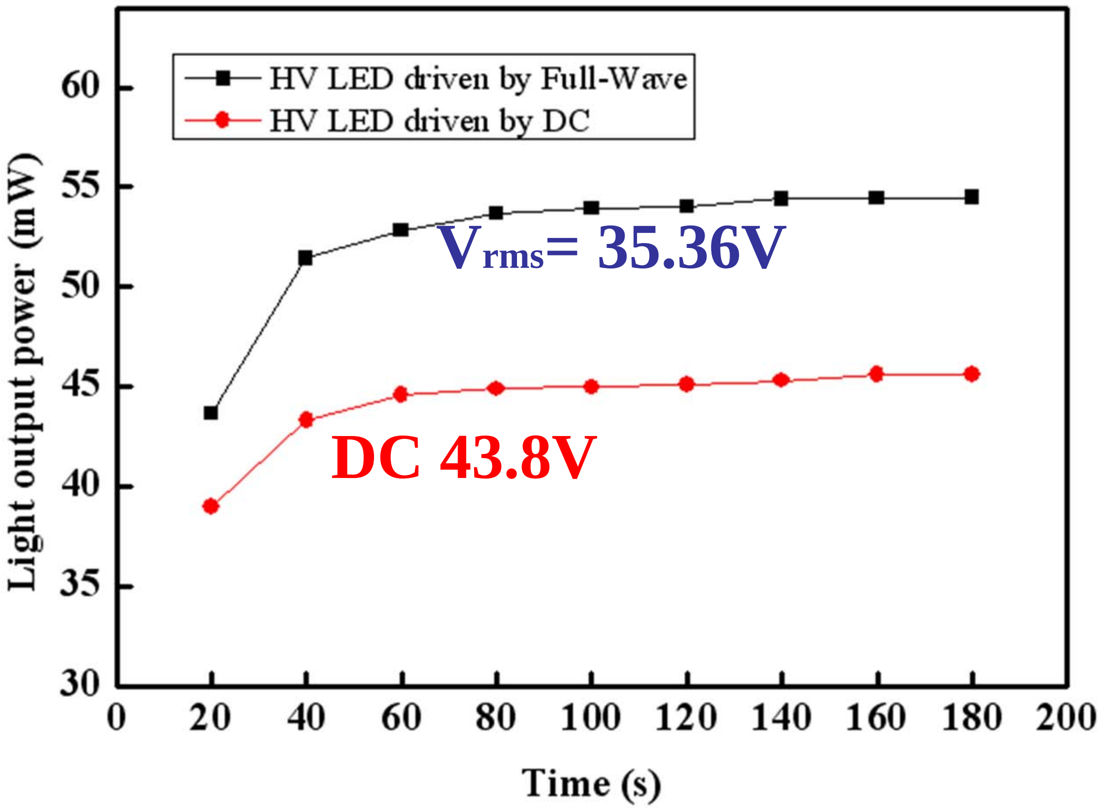


相同功率下，全波電壓 輸入之接面溫度較低，因為其輸入之功率會隨時間轉變，減少熱能的堆積



	DC （量測）	DC(模擬）	全波(量測)	全波(模擬）
輸入功率	0.28W	0.28W	0.28W	0.28W
接面溫度	73.92℃	77.26℃	65.35℃	72.11℃

定功率下之直流及全波輸入之光輸出功率



Input power: **280 mW**

Output power at 3 min

Full-Wave: **54.48 mW**

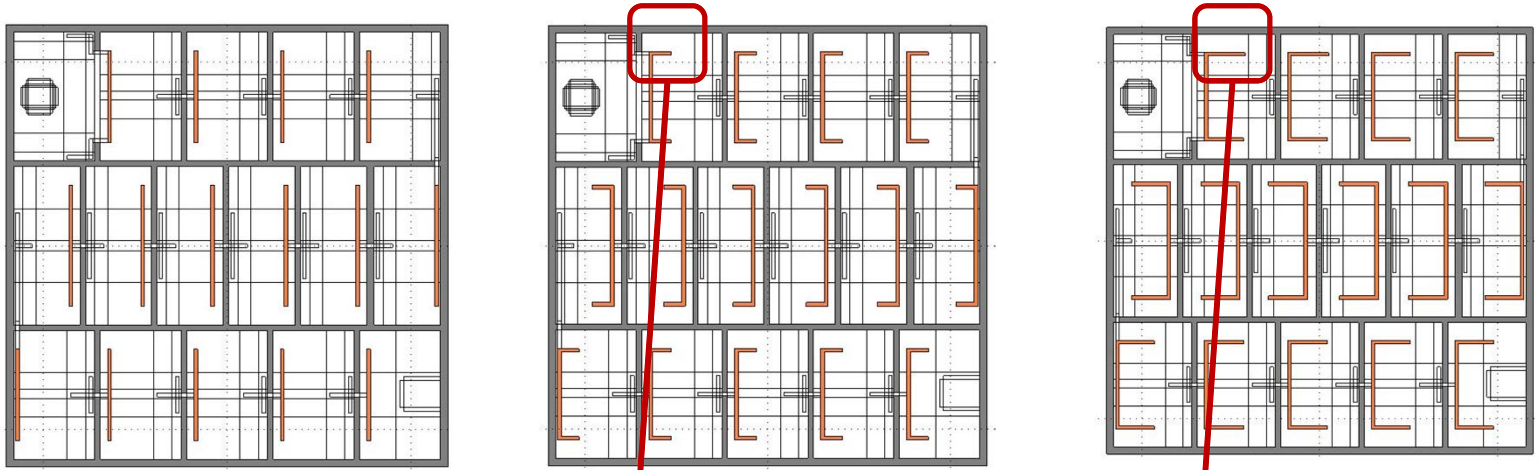
DC : **45.63 mW**

電功率= 熱+光功率

不同p 電極形狀

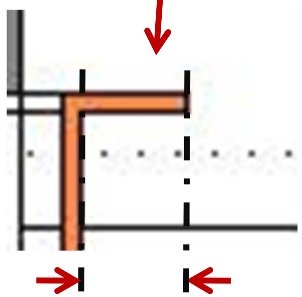
Emission Area

100% 98.6% 97.2%

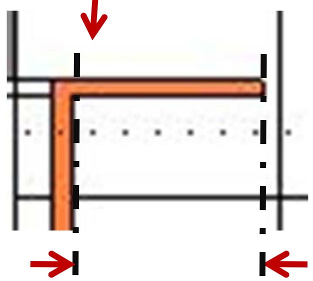


原設計

往p電極上下兩
端側向延伸

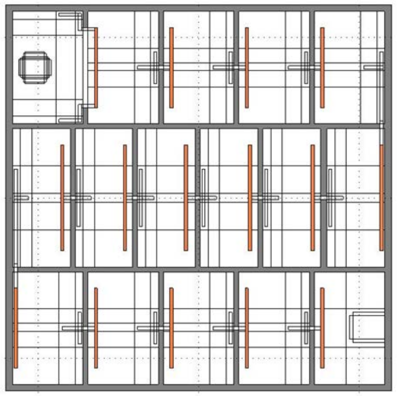
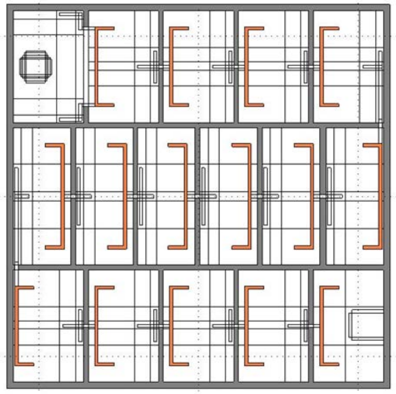
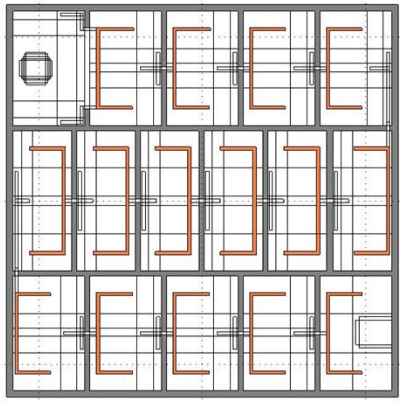
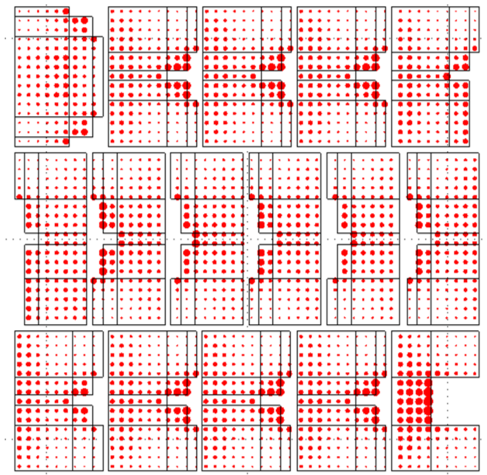
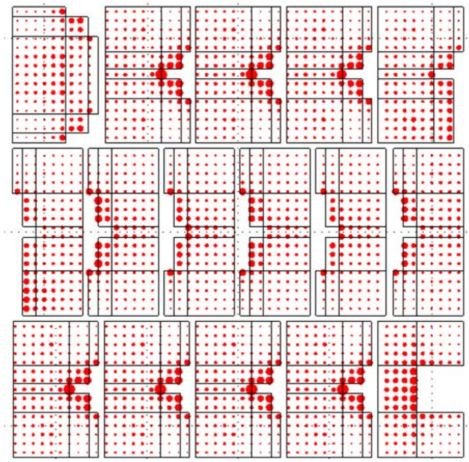
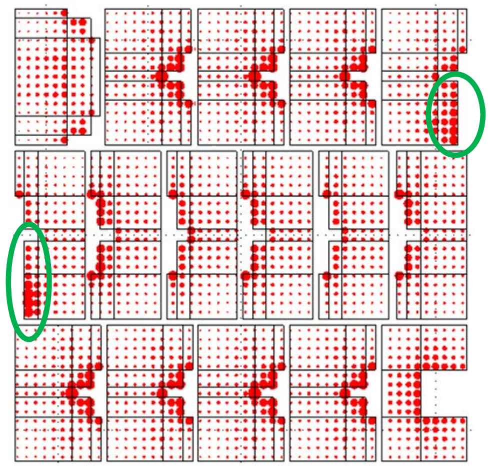


L’=50 μm



L’=100 μm

不同p 電極形狀(續)

	原設計	L'=50 μm	L'=100 μm
物理模型			
(Vrms=35.36V) 電壓峰值之電流密度			
$\Delta J\,(A/m^2)$ $J_{max}-J_{min}$	1.236 e6	1.545 e6	1.896 e6

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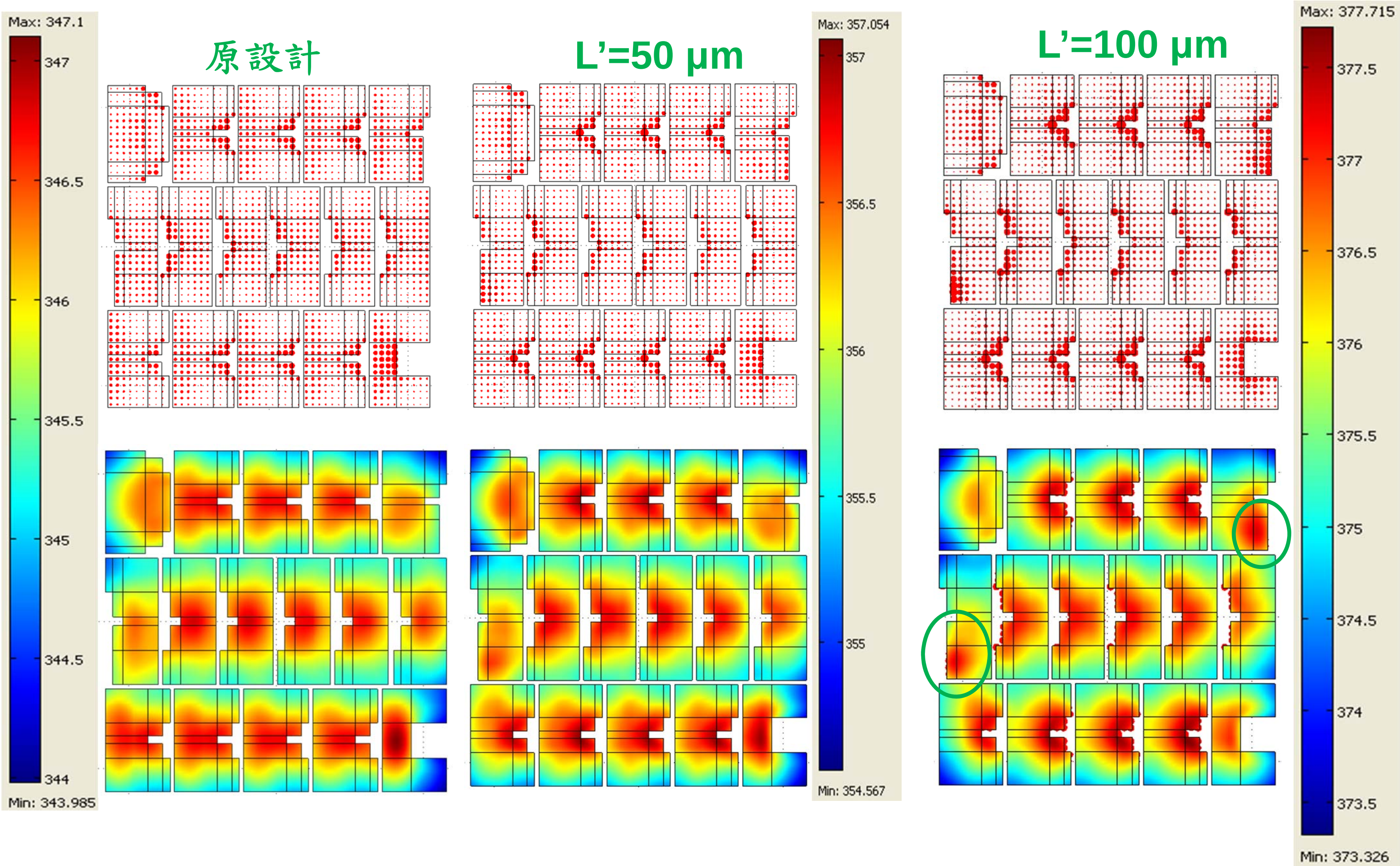
不同p 電極形狀(續)



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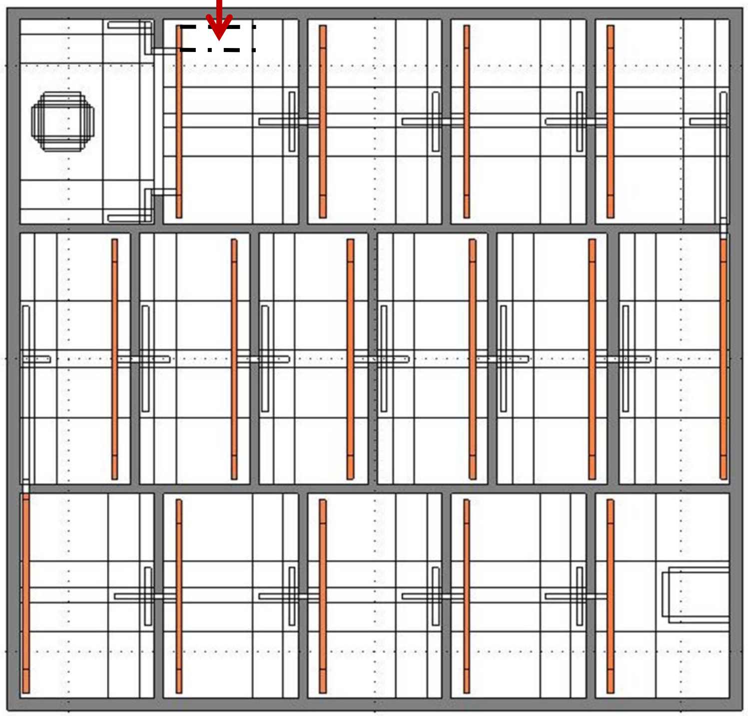
不同p電極形狀(續)

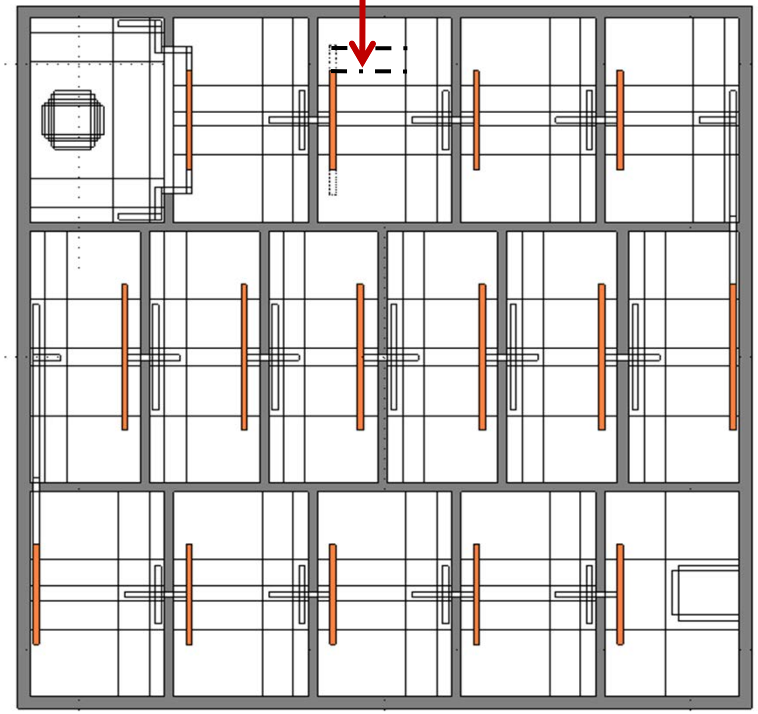
Emission Area

	L”=40 μm	L”=-40 μm
Emission Area	–98.7%	101.3%

L”=40 μm



L”=-40 μm



往p電極上下兩端縱向延伸及縮短40 μm

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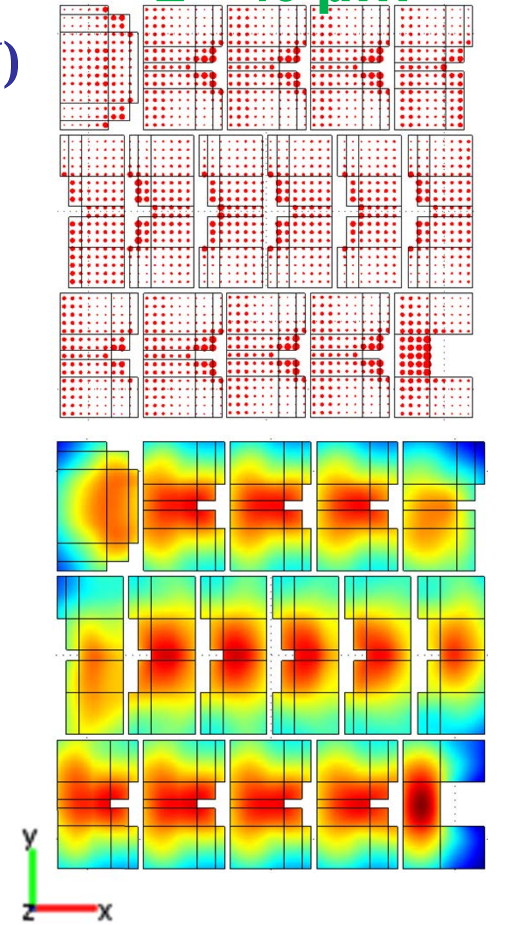
不同p電極形狀(續)

(Vrms=35.36V)

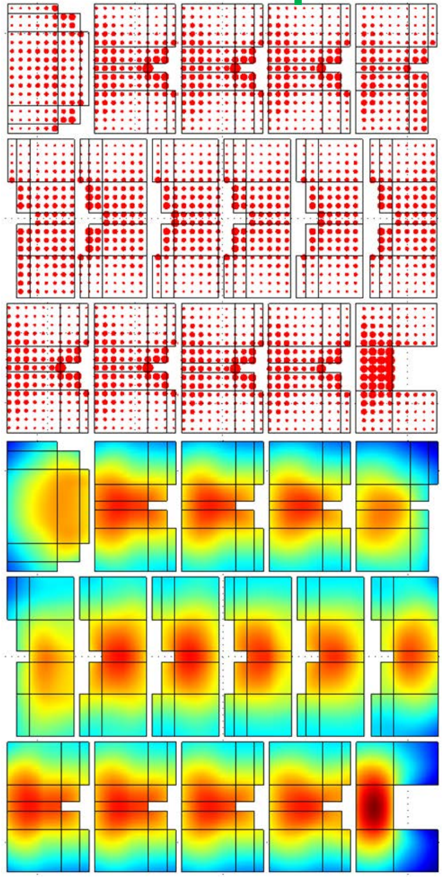
電壓峰值之電流密度

電壓峰值之溫度分佈

L”=40 μm



L”=-40 μm



$\Delta J\,(A/m^2)$

$J_{max} - J_{min}$

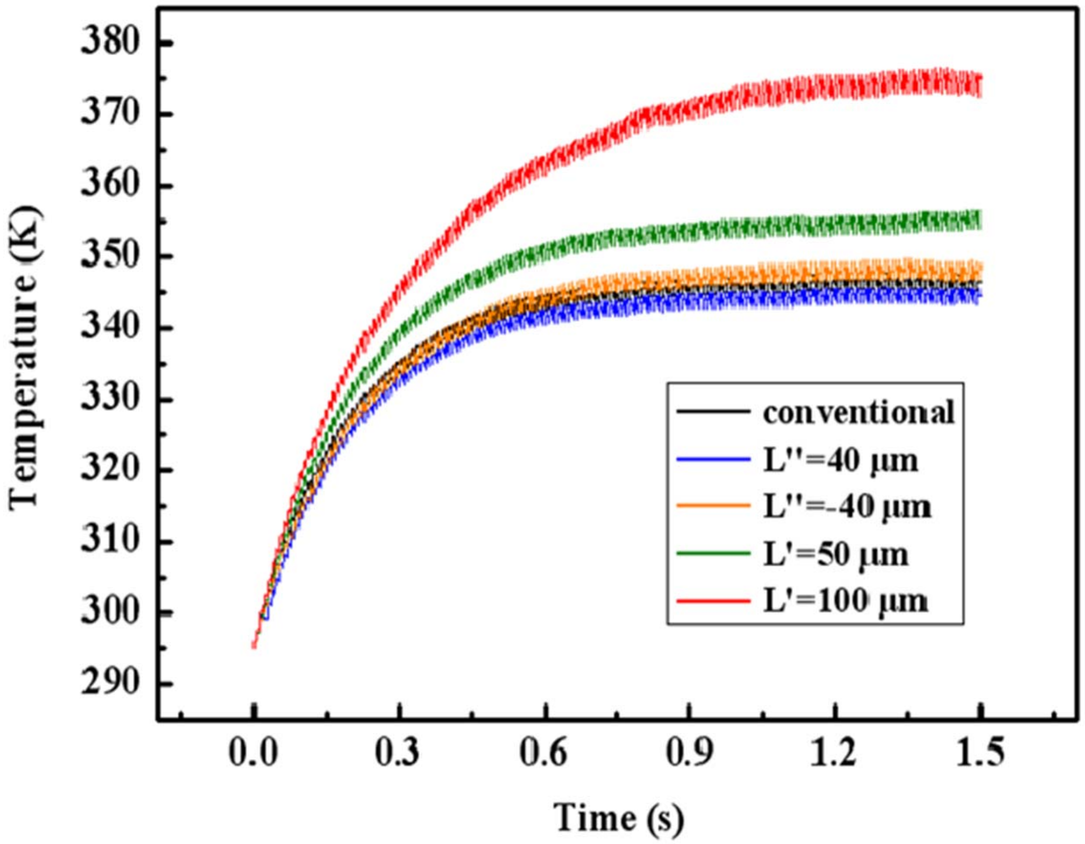
1.176 e6

1.328 e6

原設計1.236 e6

不同p電極形狀(續)

晶片活化層中心區域接面溫度隨時間變化圖(V_{rms}=35.36V)

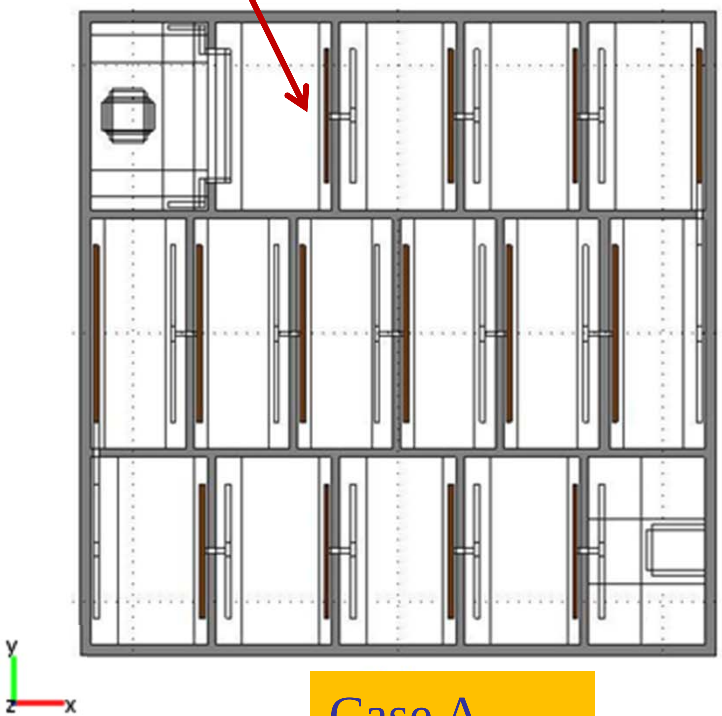


p-length	mean T_j (K)
conventional	345.1
L”=40 μm	344.2
L”=-40 μm	347.1
L’=50 μm	354.8
L’=100 μm	374.5

改變n電極形狀

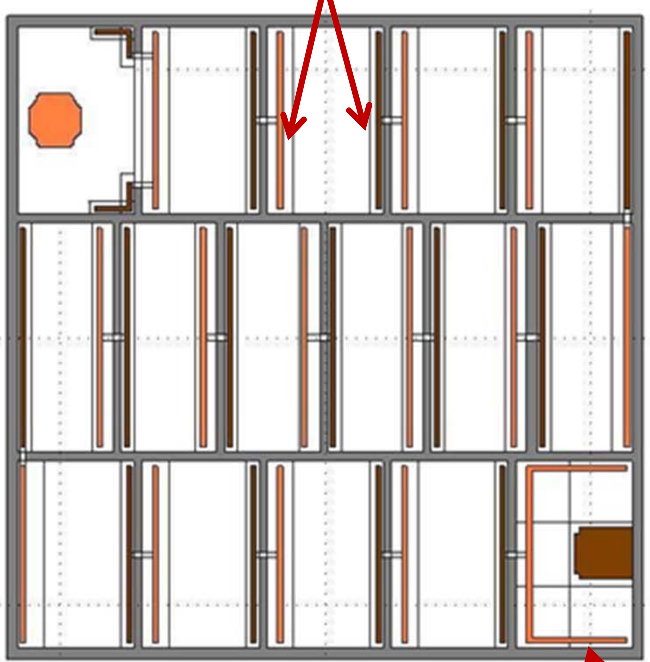
Emission Area	94.7%	93.6%

n 電極與 p 電極同長



Case A

n 電極與 p 電極皆縱向延伸 80μm



Case B

p 電極側向延伸 180μm

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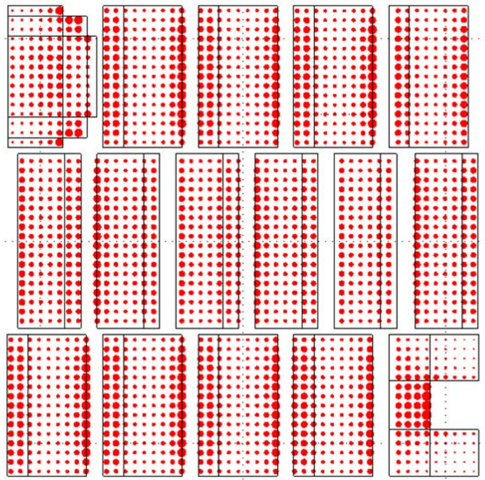
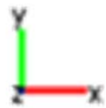
改變n電極形狀(續)

Case A

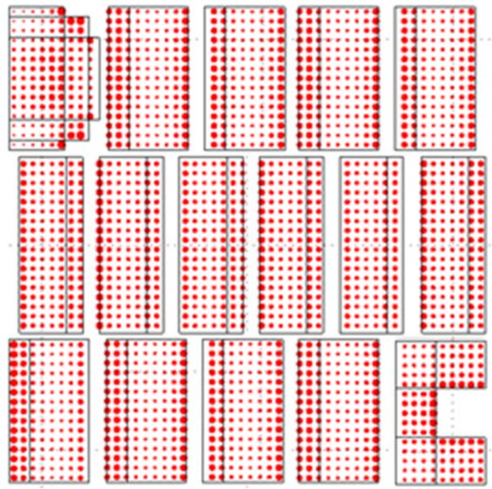
(Vrms=35.36V)

電壓峰值之電流密度

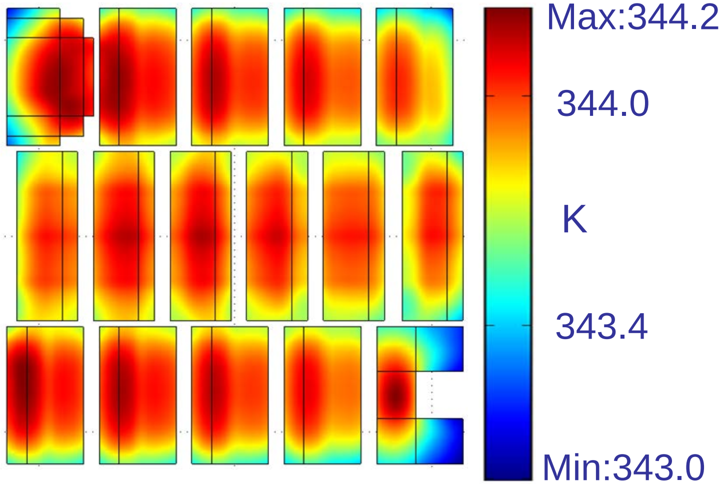


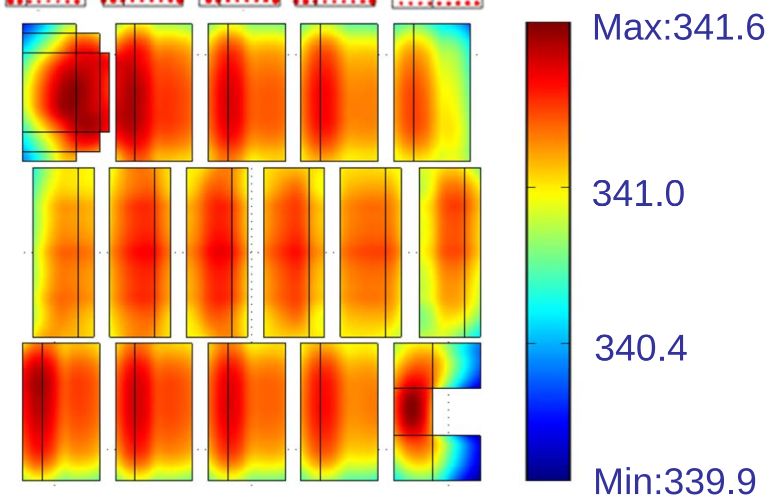


Case B



電壓峰值之溫度分布





$\Delta J\,(A/m^2)$

$J_{max} - J_{min}$

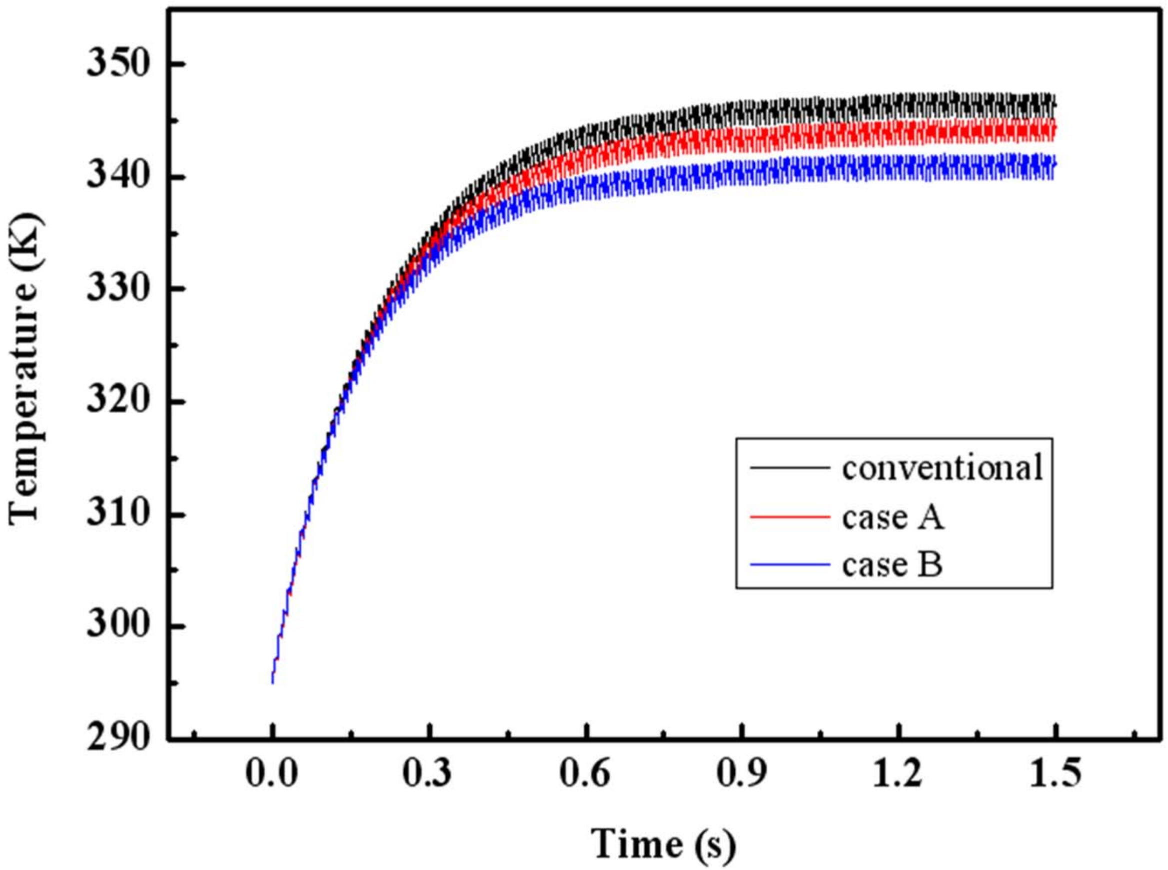
1.108 e6

0.897 e6

原設計1.236 e6

改變n電極形狀(續)

晶片活化層中心區域接面溫度隨時間變化圖(V_{rms}=35.36V)



electrode Condition	mean T_j (K)
conventional	345.1
case A	343.3
case B	340.5

結論

- 數值模擬技術可預測氮LED晶片之電流和溫度場分佈，並對晶片結構進行最佳化設計。

- 未來可與光學模擬技術結合，進行LED晶片光學特性特討，減少磊晶內光的吸收，提昇光取出效率，提高亮度。

Thanks for your attention !