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LED技術及應用發展新趨勢

洪盟淵
晶元光電

2009.05.19

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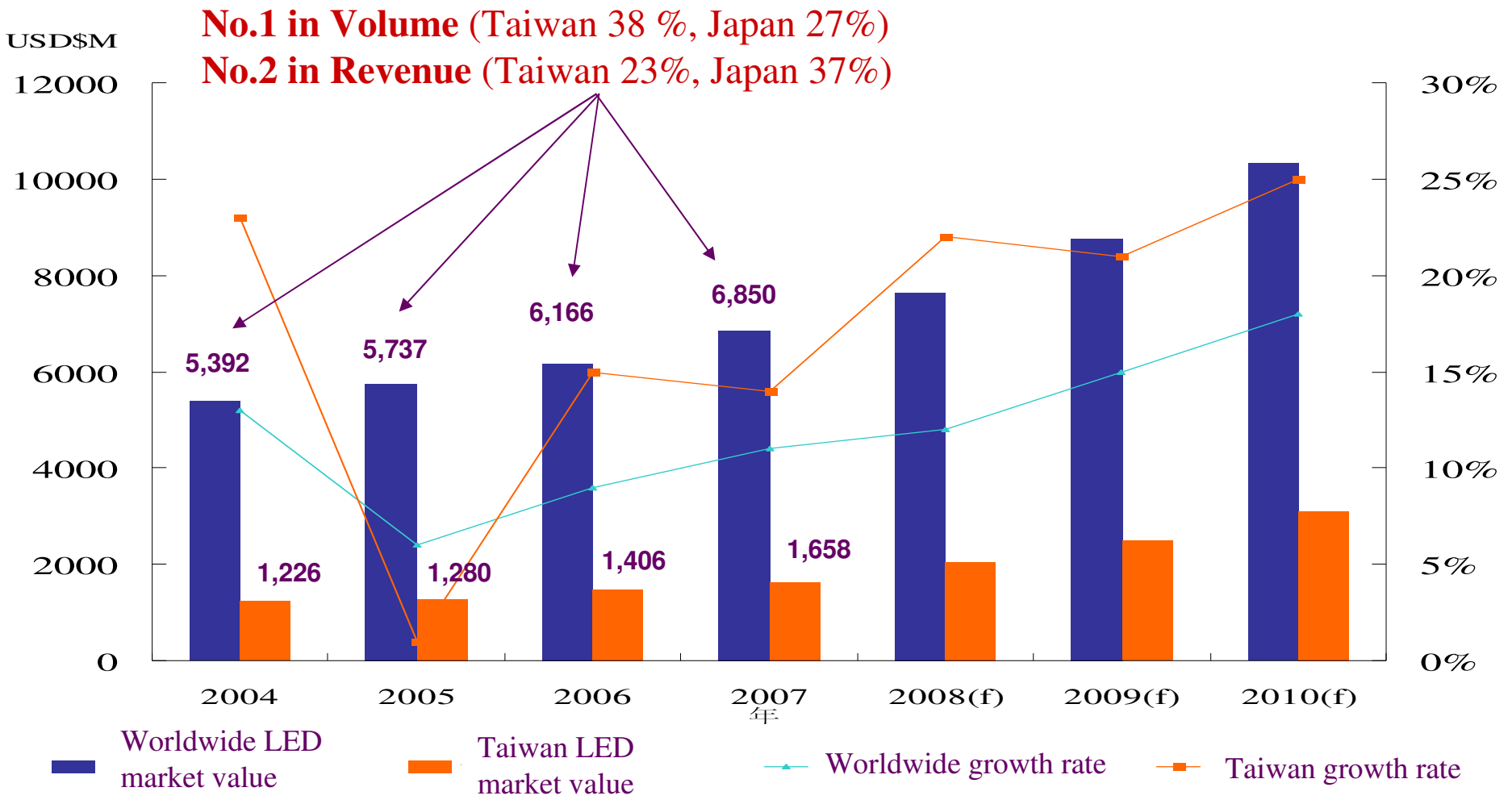
Outline

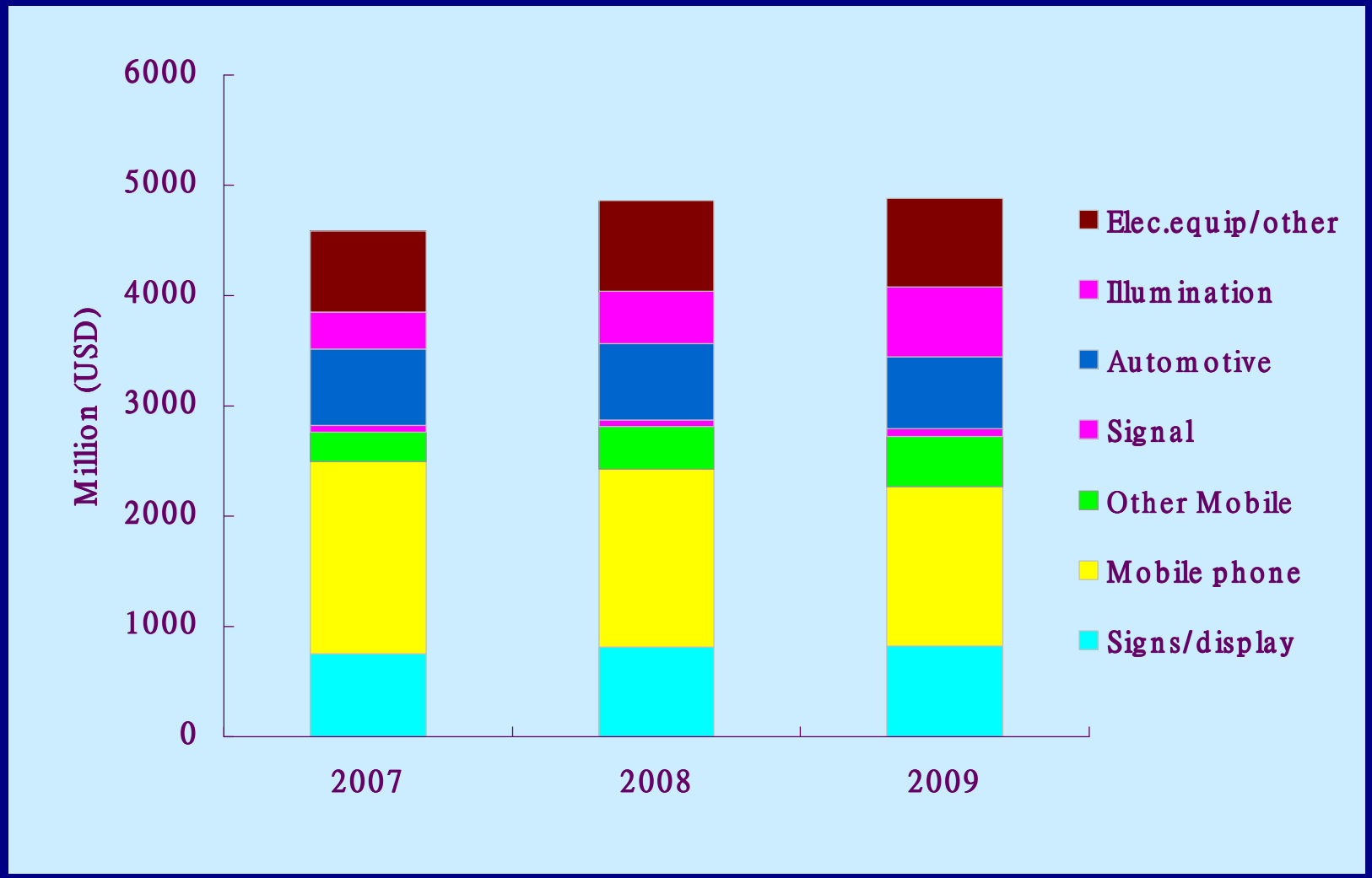
- Overview of LED Industry
- LED Applications
- Roadmap to High Efficiency at Injection High Currents
- New Technology for Solid State Lighting - ACLED

Global and Taiwan LED Market Trends



Source : ITRI/IEK(2008)

Worldwide LED Market Outlook for 2009



Source：IEK(2009)

LED Notebook Backlight Demands

全球 LED 背光需求量

單位：百萬顆

應用別	2007	2008	2009f	2010f	2011f	2012f	GAGR%(08-12)
NB	47	687	2,522	4,738	6,443	7,897	84
監視器	0	7	51	160	354	652	211
LCD TV	3	114	1,699	5,484	12,813	26,174	289
總計	50	808	4,272	10,382	19,610	34,723	156

資料：業者、DIGITIMES整理，2009/2

製表：韓青秀、游順發

In 2009, there will be around 63M of NB that will use LED backlight, assuming 40 LED in each LED backlight.

-> a 40% penetration rate

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- **LED New Applications**
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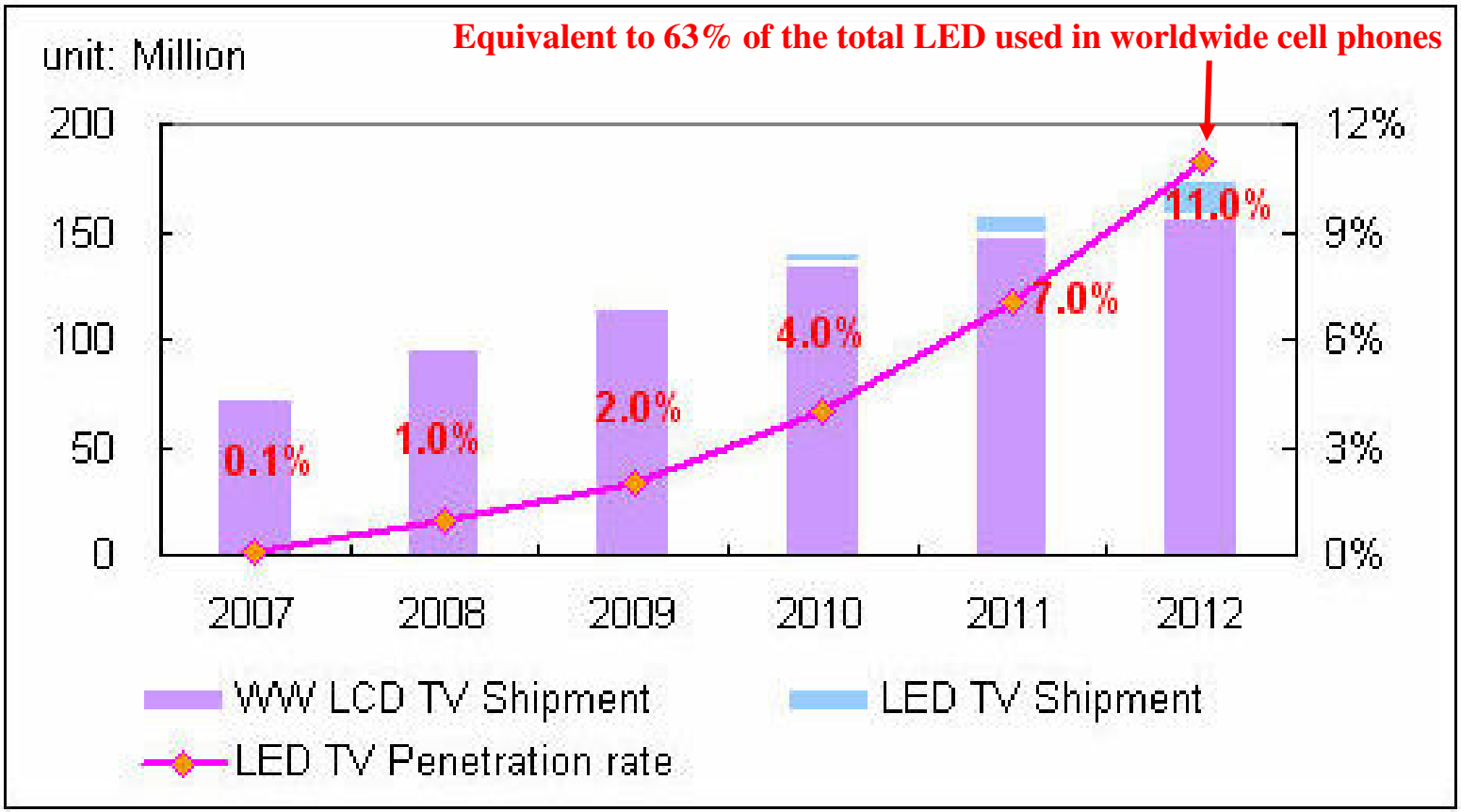
LED LCDTV Market Penetration



Source: LEDinside, Witsview

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LCD TV with LED Backlight

三星LED節能液晶電視 6月來台上市

圖2-3-3 全球最薄之LED背光源電視

DIGITIMES 2009/4/2

主要顯示器業者發展TV用LED背光所採型式

廠商	LED背光源型式	產品特色
三星電子	側光式白光LED	40吋~55吋LCD TV最薄部位6.5mm，為試製機種中厚度最薄者。
	直下式白光LED	動態對比值提升至100萬:1。
Sony	側光式白光LED	40吋LCD TV最薄部位9.9mm，為上市機種中厚度最薄者。
	直下式RGB LED	46吋、55吋仍採用high-power LED設計，考量因素為色彩管理較易。
夏普	直下式RGB LED	52吋及65吋LCD TV機身厚僅2.28公分。
Victor	側光式白光LED	32吋LCD TV最薄部位7mm。
東芝	直下式RGB LED	動態對比值達100萬:1。
友達	側光式白光LED	46吋LCD面板LED light bar數縮為2條。
	直下高密度RGB LED背光	區域控制所畫分區域細分為1,296區。
Global Lighting Technologies	側光式白光LED	LED背光源採單邊放置型式。

資料來源：各廠商，DIGITIMES整理，2009/2

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The Advantage of LED LCDTV

LED背光應用在LCD TV優勢

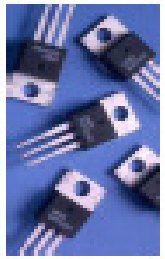
- 廣色域：
  - RGB 3色LED背光NTSC(u' v')可達140%以上。
  - 白光LED NTSC(u' v')可作到約95%。
- 調整色溫：
  - 藉由調整RGB LED電流比例，使色溫範圍達到LCD TV要求。
  - 白光LED可利用螢光體比例的組合，達到某特定波長。
- LCD顯示器可呈90度方向轉動：
  - CCFL型顯示器若由橫向放置轉為直立放置，則CCFL燈管內的汞會向下流積。
  - LED燈源則無上述問題。
- 可對應至超大型LCD顯示器：
  - CCFL型燈管有長度限制
  - LED由單一光源所組合而成，背光模組易作到大型化。
- 薄型化：
  - 尤其是側光式LED能達最佳薄度。
- 區域控制(2D Dimming)可能：
  - 依畫面內容明暗程度作輝度調整
  - 動態對比值提升
  - 降低耗電量
- RGB LED-Color Sequential：
  - 不需使用CF
    - LCD面板透光率提高3倍。
    - 降低耗電量
  - 解析度提高3倍
  - LED光利用效率高
    - 需某特定顏色時，僅需點亮該顏色LED光源。
- 瞬間點滅：
  - 因LED光源點滅速度快，可改善LCD TV動畫表現。
- 啟動電壓低
  - LED driver IC僅需低電壓驅動
  - 驅動CCFL的Inverter須使用高電壓、高電流。
- 其它：
  - 輝度易調整、無汞、無紫外線等...

資料來源：DIGITIMES，2008/7

Historical Evolution for Solid State Technology

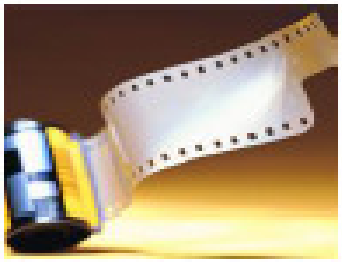
Vacuum Tubes → Transistors

1940s – 1950s



CRT → Flat Panel

1990s – 2000s

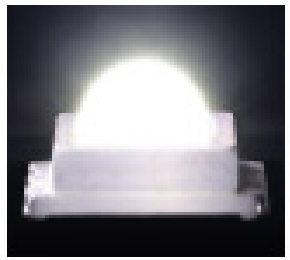


Film → Flash Memory

1990s – 2000s

Light Bulbs/ Fluorescent → Solid State Lighting

2000s – …



Government Policies in Driving SSL

2009	Taiwan	**Plan to replace the incandescent light bulb with LED lamp at 2009 Q1 in government buildings, and are not allowed to manufacture and use incandescent light bulb completely starting from 2012**
2010	Australia	Plan to ban the incandescent lamp after 2010
	European Union	Plan to ban (producing and using) the incandescent lamp after 2010
2012	Japan	The government announced at 2008.04.05. The incandescent light buibs will be completely phased out before 2012
	Canada	Plan to ban using the incandescent lamp after 2012
	California	will phase out the use of incandescent bulbs by 2018.
	England	Plan to eliminate incandescent lamp gradually by 2012

Business Model - Vertical Integration
Solid State Lighting

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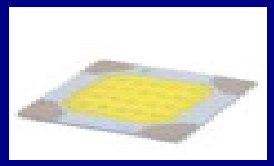
Chip



Pkg Devices

Module

Applications

Osram Opto

Osram Sylvania

Lumileds

Philips-
TIR,
PLI,
Color
Kinetics

Nichia

GE

Lumination

Toyada Gosei

Lexedis

ZUMTOBEL

Tridonic
Acto

Cree-
Cotco

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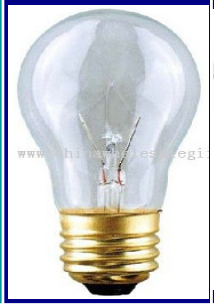
Retail Light Source Survey

Type	Incandescent			PL	Fluorescent		CFL			LED
model	-	MR-16	PAR	2 / 4 pin	T8	T-5	T3-E27	2U-E27	T2-E14	MR-16
										
Lm/W	~15	25~35(Xe)	6~15	65~75	60~95	85~95	65~70	50~65	50~55	55~65
W/Pkg	5~100	20~50	50~150	18~30	20~60	14~54	13~28	13~28	5~10	2~5
Lm/Pkg*	~600	~500	~900	~1300	~3000	~3000	~1400	~1200	~350	~250
W/$	2~9	1	0.5	0.12	0.3~1	0.06~0.13	0.14	0.17	0.05~0.08	0.005
Lm/$*	~60	~20	~5	~9	~30	~8	~10	~10	~3	~0.3
P.F	-	-	-	**	**	**	57%	57%	~55%	-
Lifetime	~1000	~2000	~2500	>12000	8000	10000	3000	3000	3000	>20000
Color. T	Warm	Warm	Warm	Tunable	Tunable	Tunable	Tunable	Tunable	Tunable	Tunable
CRI	>80	>85	>85	>80	~70	>80	~70	~70	~70	>75

* on average ** depends on ballast ** All price in NT$

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LED Lighting Applications

13W LED
Light Bulb

Cree Down
Light Module

MR16

EverLight Street
Light

Delta Solar Street Light

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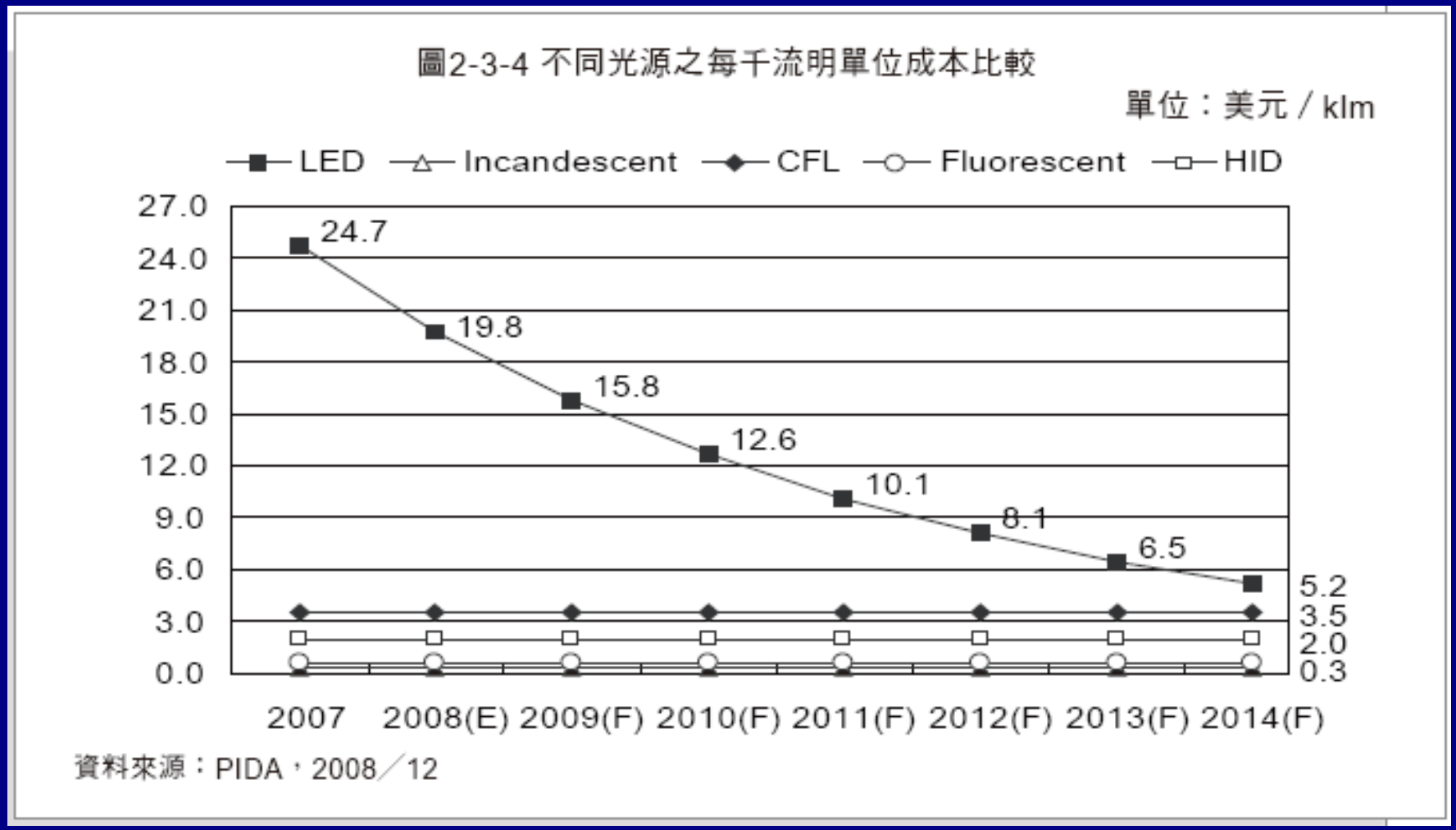
Cost Analysis for Different Lighting Sources



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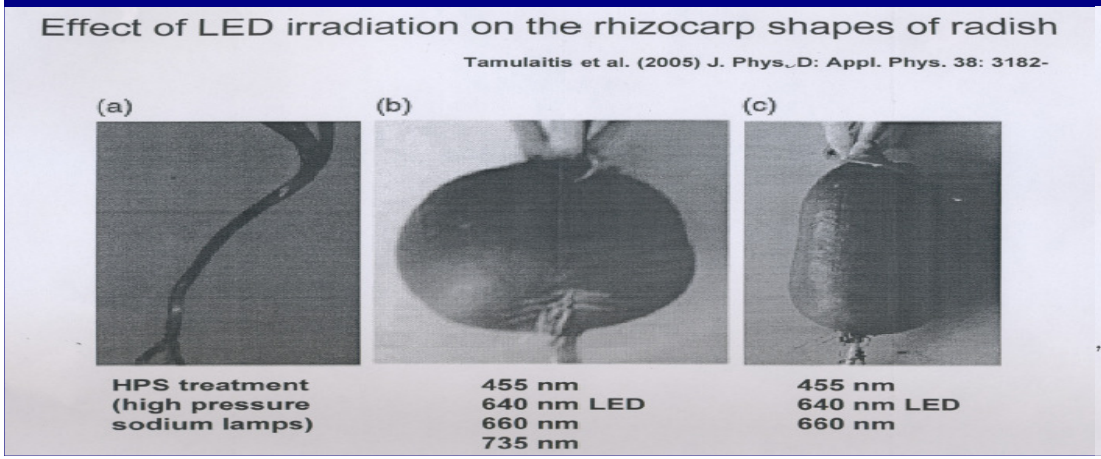
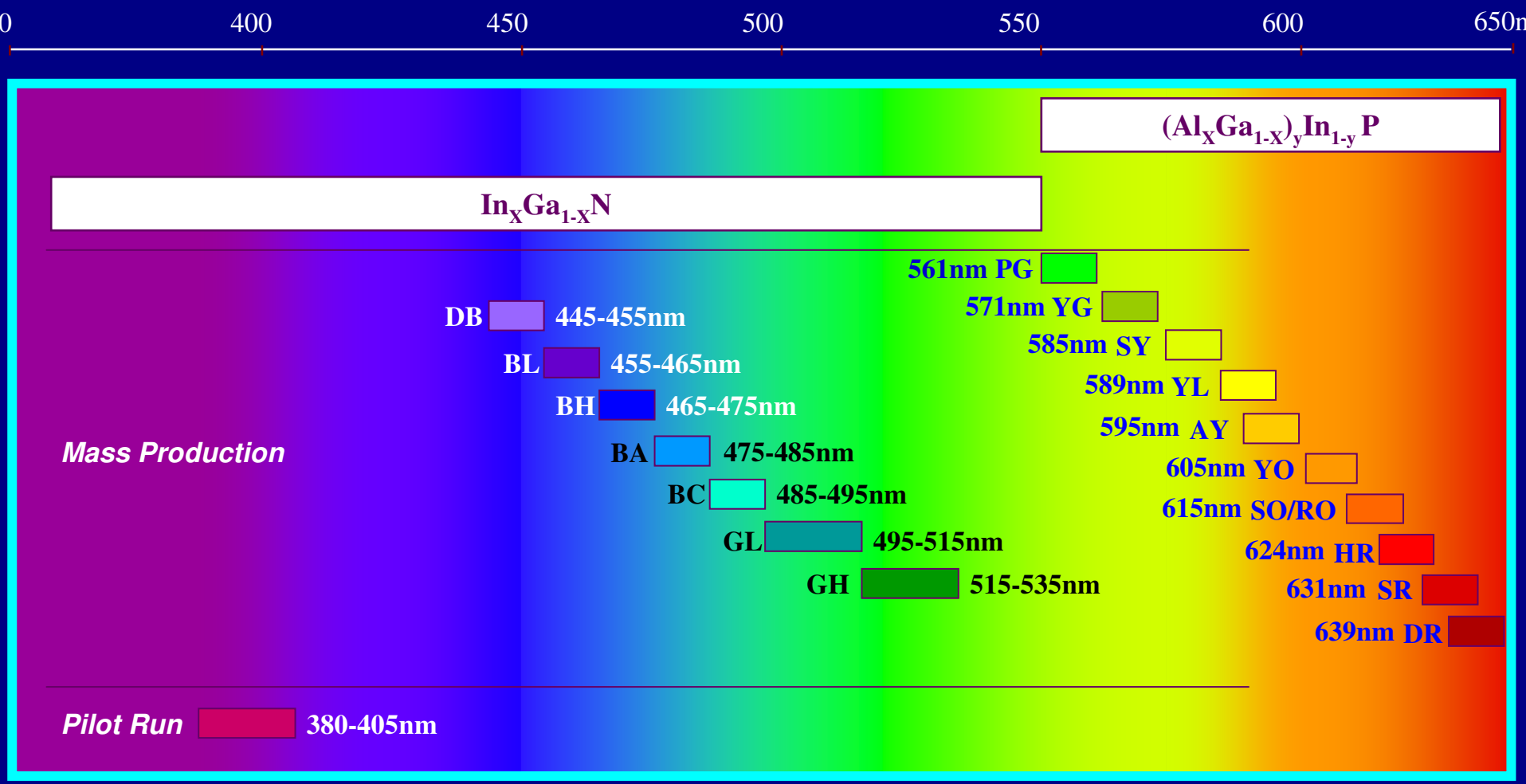
光譜與植物發育的關係

光譜範圍	對植物生理的影響
280~315nm	對形態與生理過程的影響極小
315~400nm	葉綠素吸收少，影響光周期效應，阻止莖伸長
400~520nm(藍)	葉綠素與類胡蘿蔔素吸收比例最大，對光合作用影響最大
	色素的吸收率不高
520~610nm	葉綠素吸收率低，對光合作用與光周期效應有顯著影響
610~720nm(紅)	吸收率低，刺激細胞延長，影響開花與種子發芽
720~1000nm	轉換成為熱量



Epistar HB LED Product Line-up



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Efficiency Evolution of Light Sources

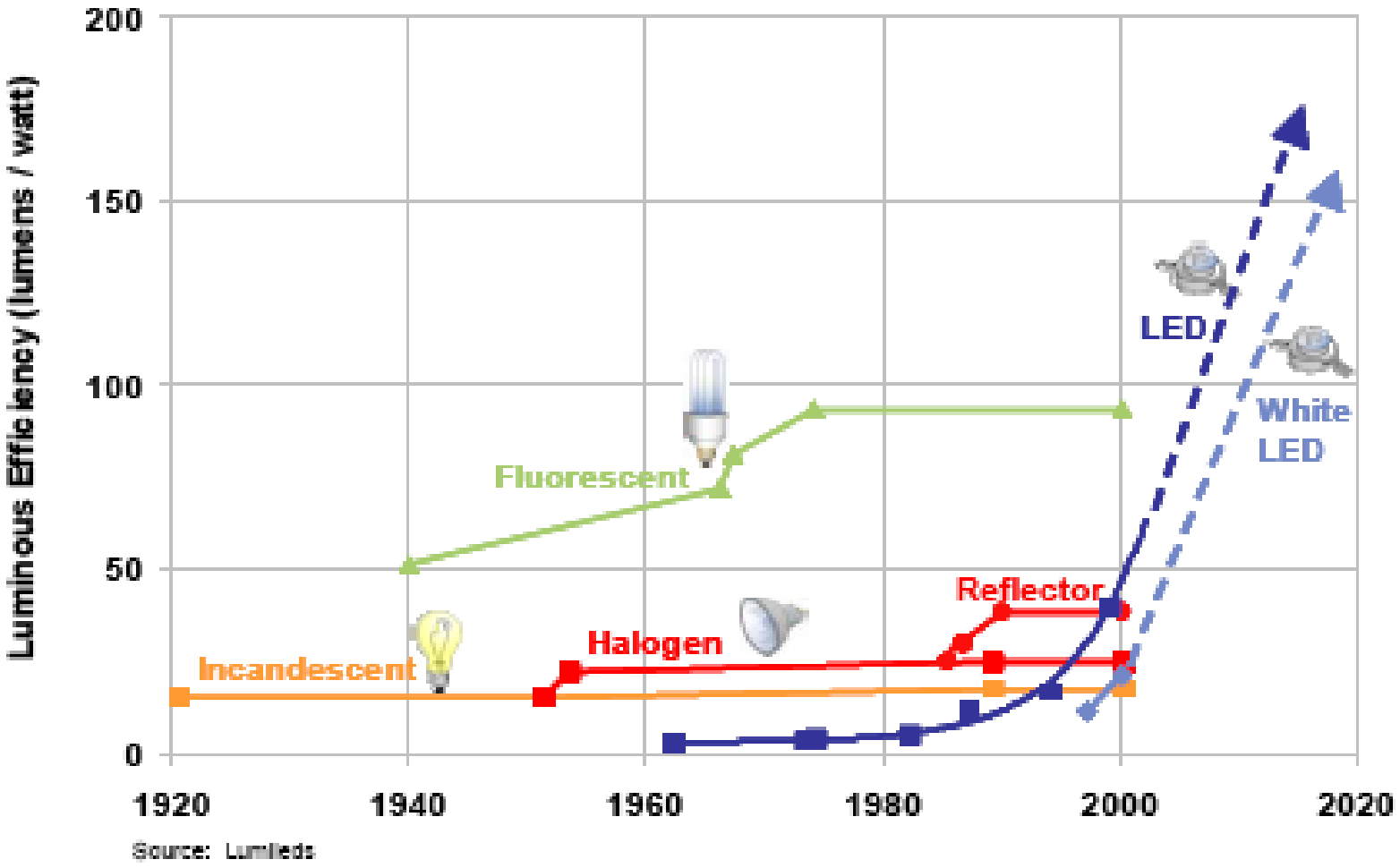

Figure 2.1: Historical and Predicted Efficacy of Light Sources
Source: Lumileds.

Courtesy of Department of Energy, USA

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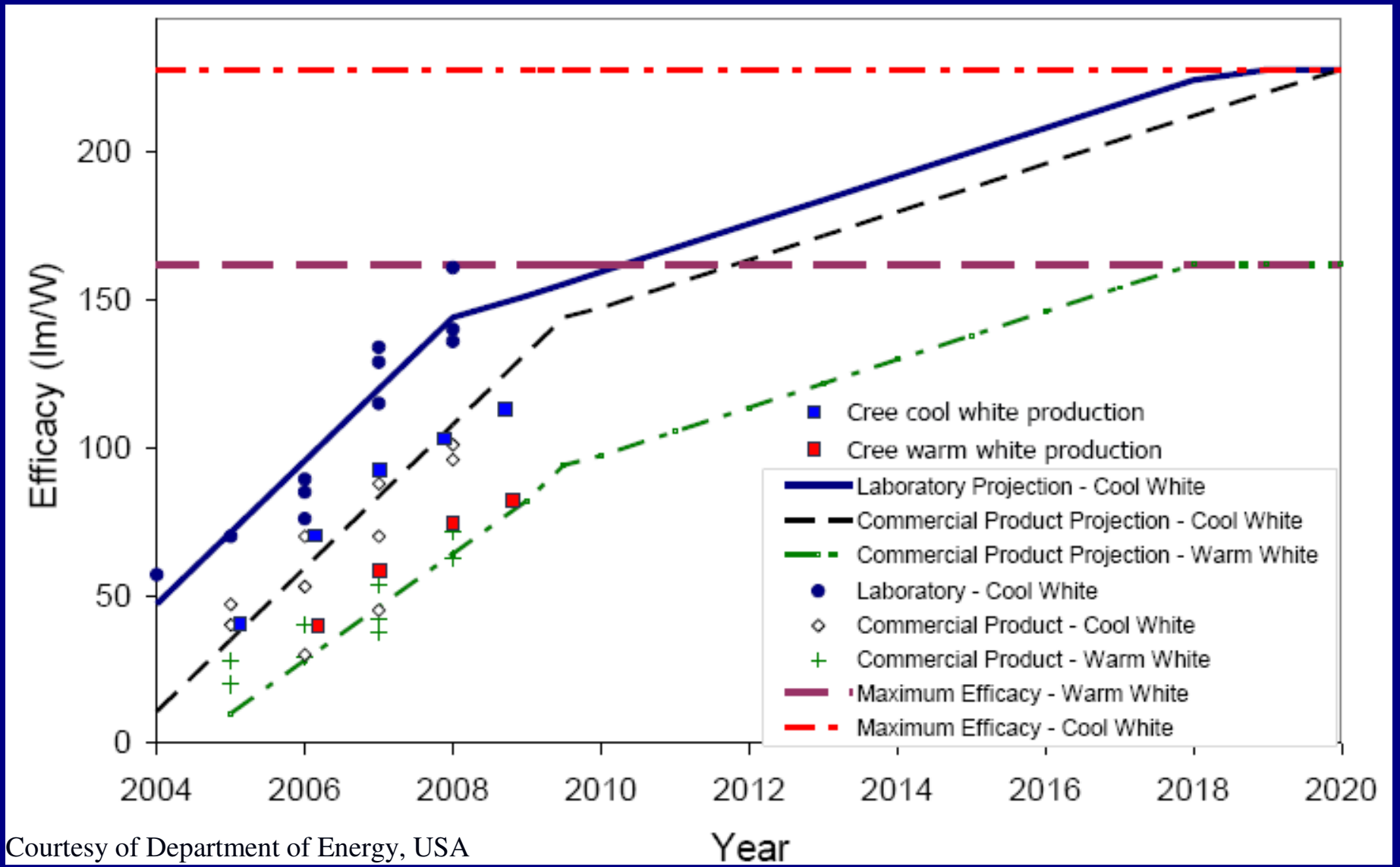
Efficiency Roadmap (DOE)



Courtesy of Department of Energy, USA

Luminous Efficiency

✓ Luminous Efficiency (lm/W) = η_{pack} X η_{phos} X η_{elec} X η_{int} X $\eta_{extract}$

Where

η_{pack} : Packaging Efficiency (optics design)

η_{phos} : Phosphor Conversion Efficiency (phosphor design)

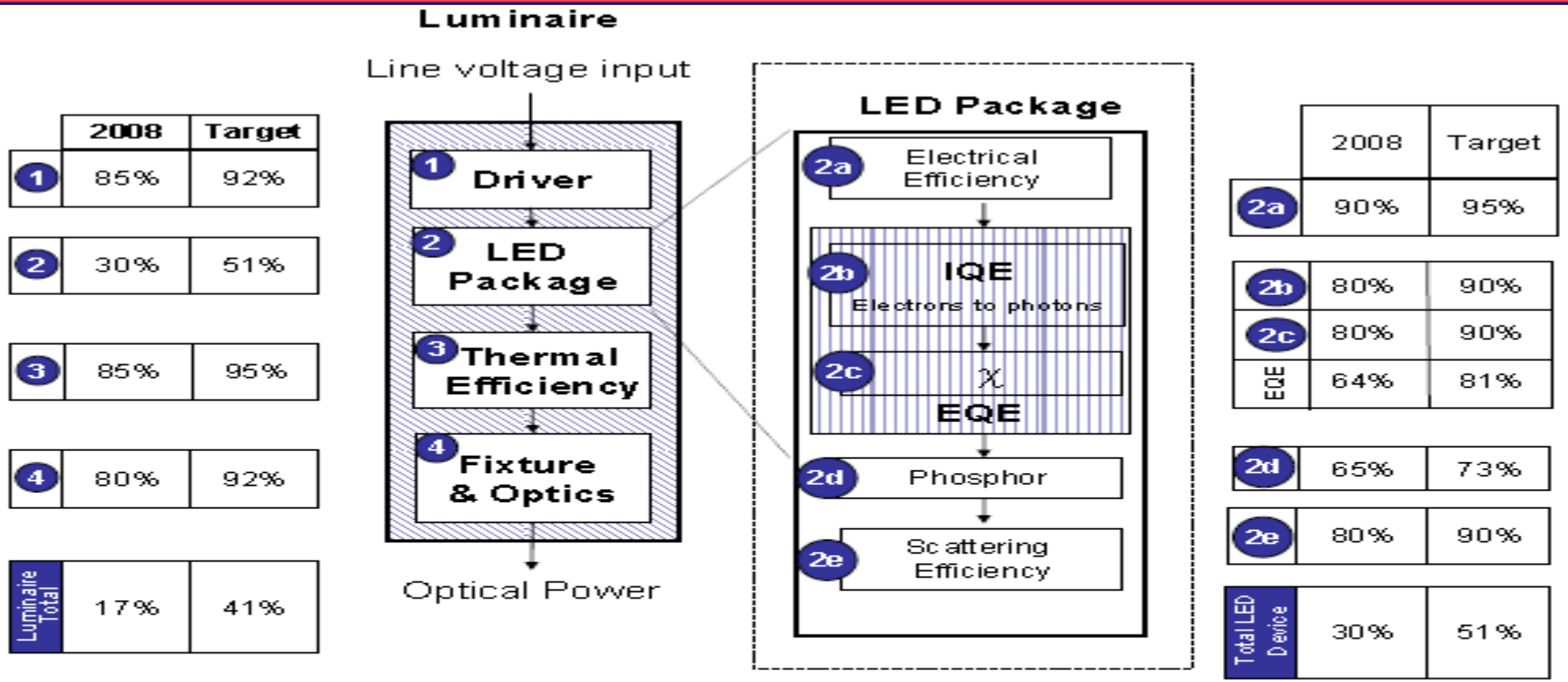
η_{elec} : Electrical Efficiency (V_f and injection efficiency)

η_{int} : Internal Quantum Efficiency (Epi layer design and quality)

$\eta_{extract}$: Light Extraction Efficiency (LED chip structure and device design)

☞ $\eta_{ext} = \eta_{int} \times \eta_{extract}$ is the External Quantum Efficiency (EQE)

Efficiency Breakdown (Phosphor-Converting LED)



	2008	Target
1	85%	92%
2	30%	51%
3	85%	95%
4	80%	92%
Luminaire Total	17%	41%

	2008	Target
2a	90%	95%
2b	80%	90%
2c	80%	90%
EQE	64%	81%
2d	65%	73%
2e	80%	90%
Total LED Device	30%	51%

Figure 4.5: Phosphor-Converting LED - Current and Target Luminaire Efficiencies for Steady State Operation

Source: LED Technical Committee, Fall 2008

Note:

1. The target assumes a CCT of 4100K and CRI of 90. Current CCT: 4100-6500K, CRI: 75
2. The target for 2d includes the loss due to the Stokes shift (90% quantum yield times the ratio of the average pumped wavelength and the average wavelength emitted); the value here is typical of a blue diode/yellow phosphor system
3. The shown efficiency allocation is only one method of achieving the 41% luminaire efficiency target.

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How Achievable is 150 lm/W ?

How Achievable is 150 lm/W ?

LUMILEDS

	PC White	
	Today*	**Future**
C_{ext} (%)	~80	**~90**
IQE (%)	~55	**~90**
EQE (%)	~45	**~80**
V_f (V)	~3.3	**~2.9**
WPE (%)	~35	**~75**
LE (lm/W)	~70	**~150**

* High performance commercial "cool white" LED.

1mm^2 chip driven at 350mA.

- IQE must increase by >1.5X
- This table assumes a phosphor conversion on 200 lumens/optical Watt for "cool" white (CCT >5000).
- For "warm" white (CCT 3000 – 4000) the conversion is significantly lower and requires development. This is an issue for illumination.
- To achieve 1000 lumen source drive current must be ~2A which reduces luminous efficacy (LE).

M. George Craford, March 2007, APS

Improvement of Luminous Efficiency

- ✓ Internal Quantum Efficiency - droop issue
  - Epitaxial quality
  - Quantum well/barrier design
- ✓ Light Extraction Efficiency
  - Light scattering/diffraction in or on the LED chip
  - Reduce the absorption of the reflected/scattered light.
- ✓ Electric Efficiency
  - Current spreading (crowding)– “Finger” and Transparent Contact Metal Layer (ITO)
  - Reduce forward voltage
- ✓ Phosphor Conversion Efficiency
- ✓ Packaging Efficiency

Droop Issue - Attributions

- ✓ Droop: External quantum efficiency drops as injection current increases.
- ✓ Droop attributions
  - Phonon-assisted Auger Recombination - Philips Lumileds, OSRAM
  - Piezoelectric (Polarization) effects in the quantum wells - RPI, Samsung Electro-Mechanics, Virginia Commonwealth Univ
  - Non-radiative recombination - West Virginia University
  - Defects

Device Design Approaches

- ✓ Better current spreading
  - ☞ New transparent oxide
  - ☞ Optimized contact finger design
  - ☞ Thicker n-GaN
- ✓ Better light extraction
  - ☞ Surface texturing
  - ☞ Interface light path design
- ✓ Reduce forward voltage, V_f
  - ☞ Increase p-GaN doping concentration
  - ☞ Reduce contact resistance

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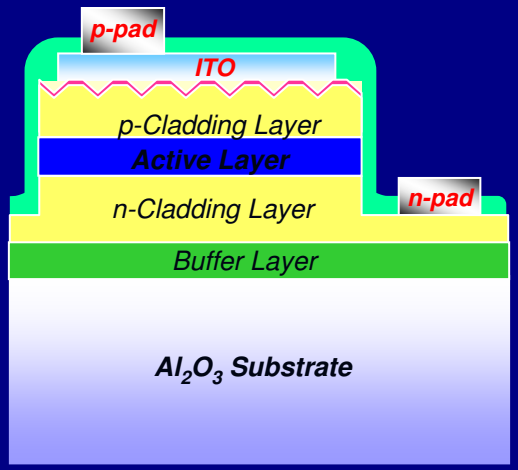
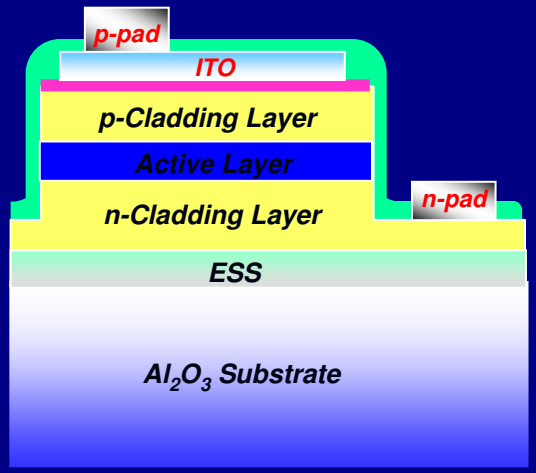
Power Chip Portfolio

Venus-Series



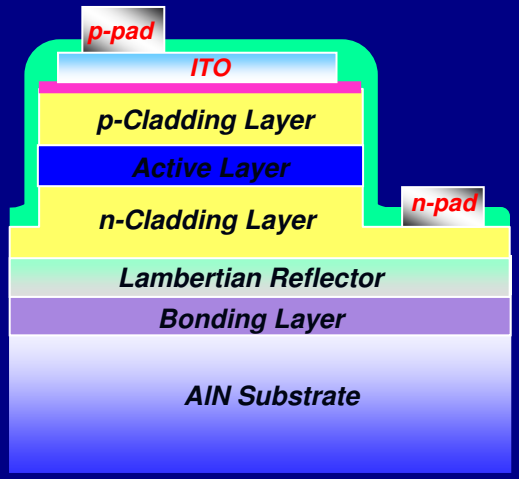
- *ITO on rough p-GaN*
- *Leaf vein finger design*

Generic



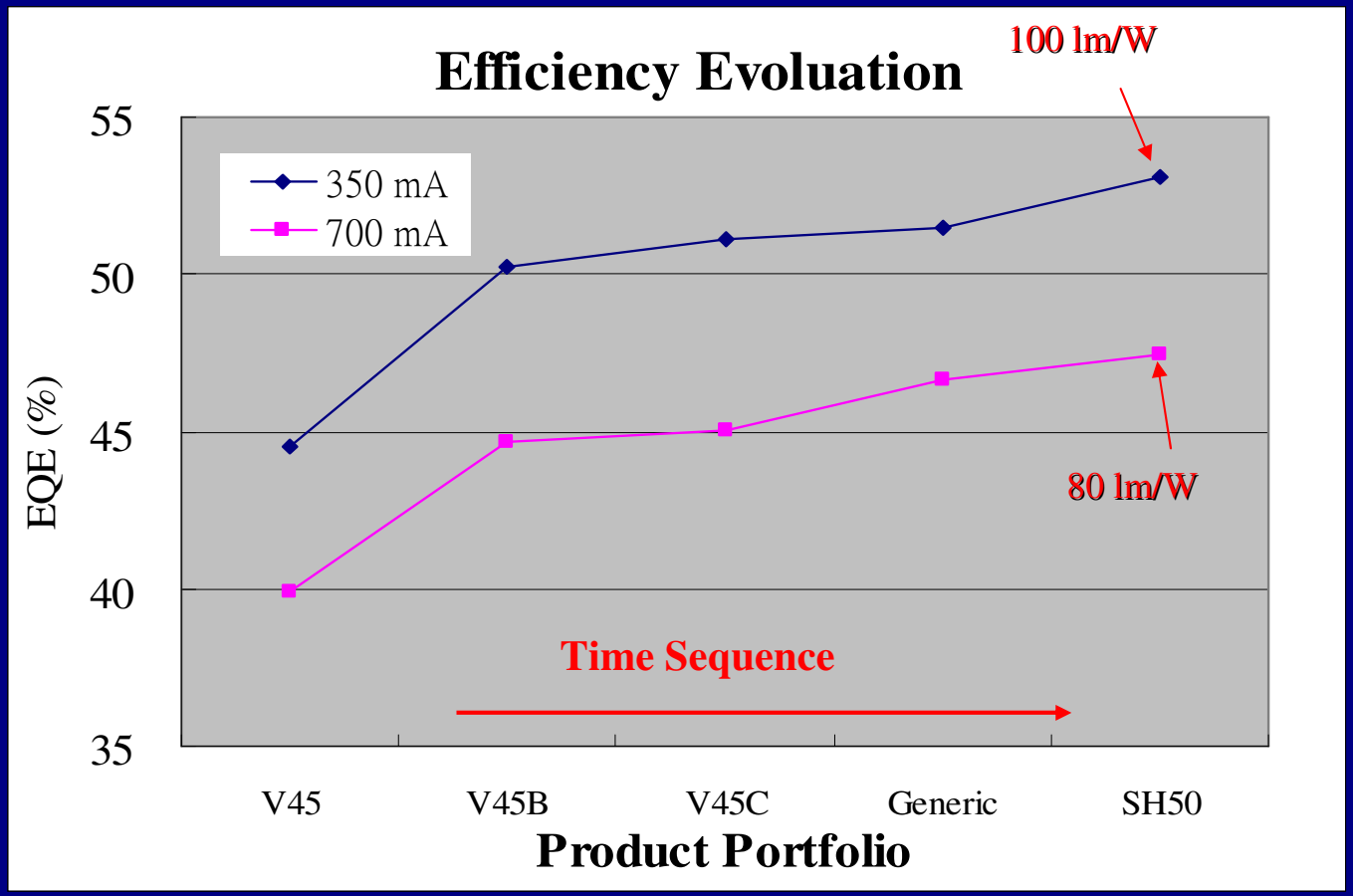
- *ITO on flat p-GaN*
- *ESS technology*

Saturn-H Series



- *ITO on flat p-GaN*
- *Lambertion reflector*
- *High $k_{thermal}$ substrate*
- *Separation of heat dissipation and current path*

Evolution of Power Chip Performance



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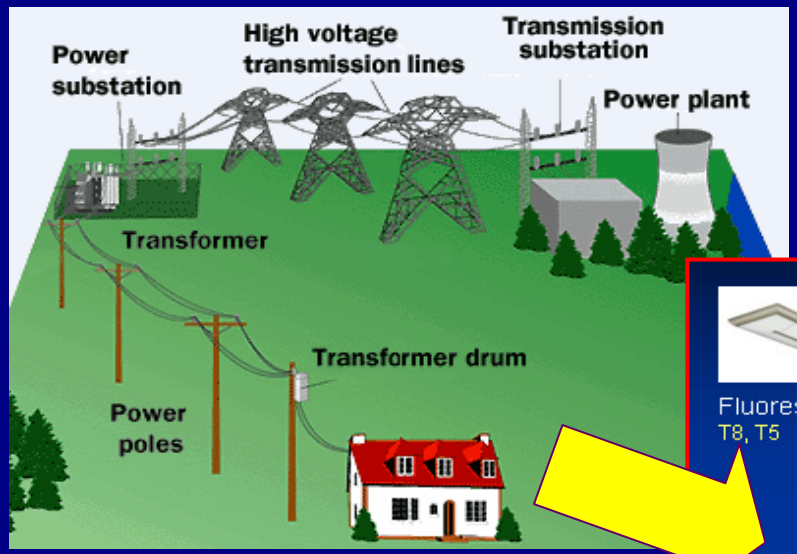
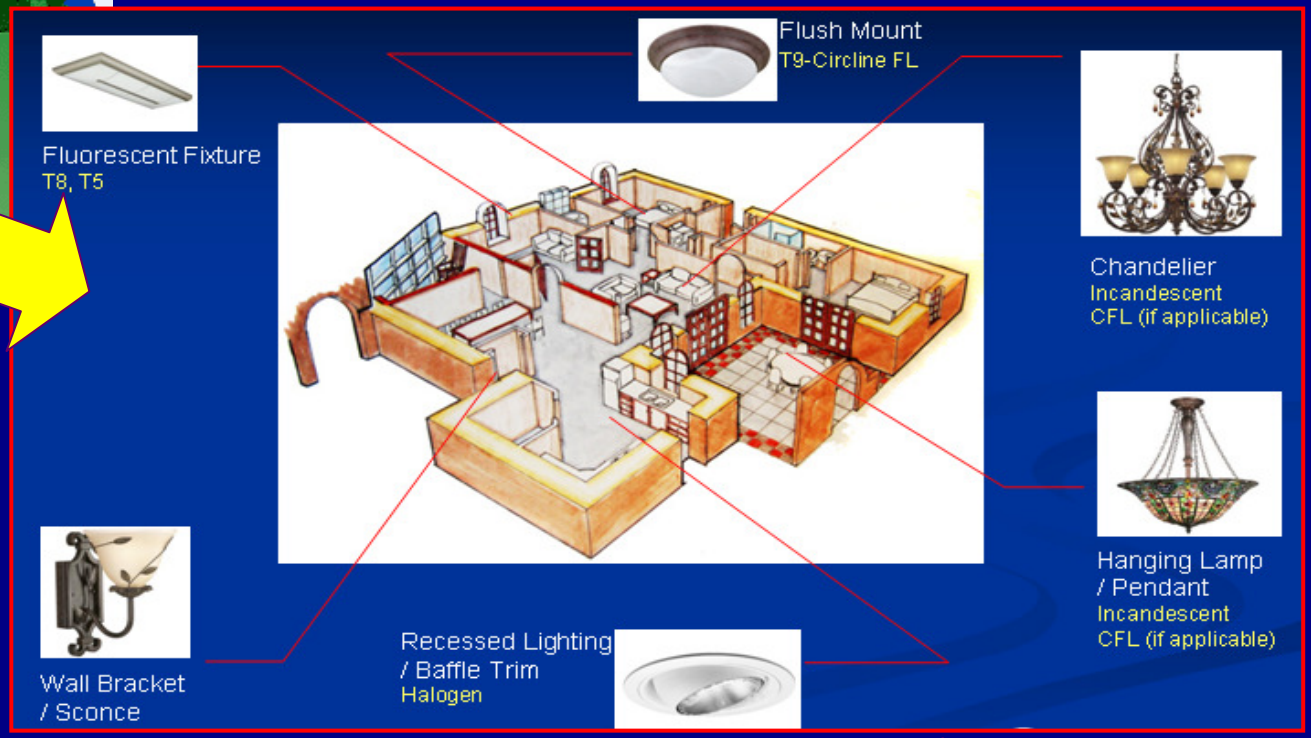
From Power to Illumination



Most of the lighting source are powered by AC Power!!!



AC is everywhere

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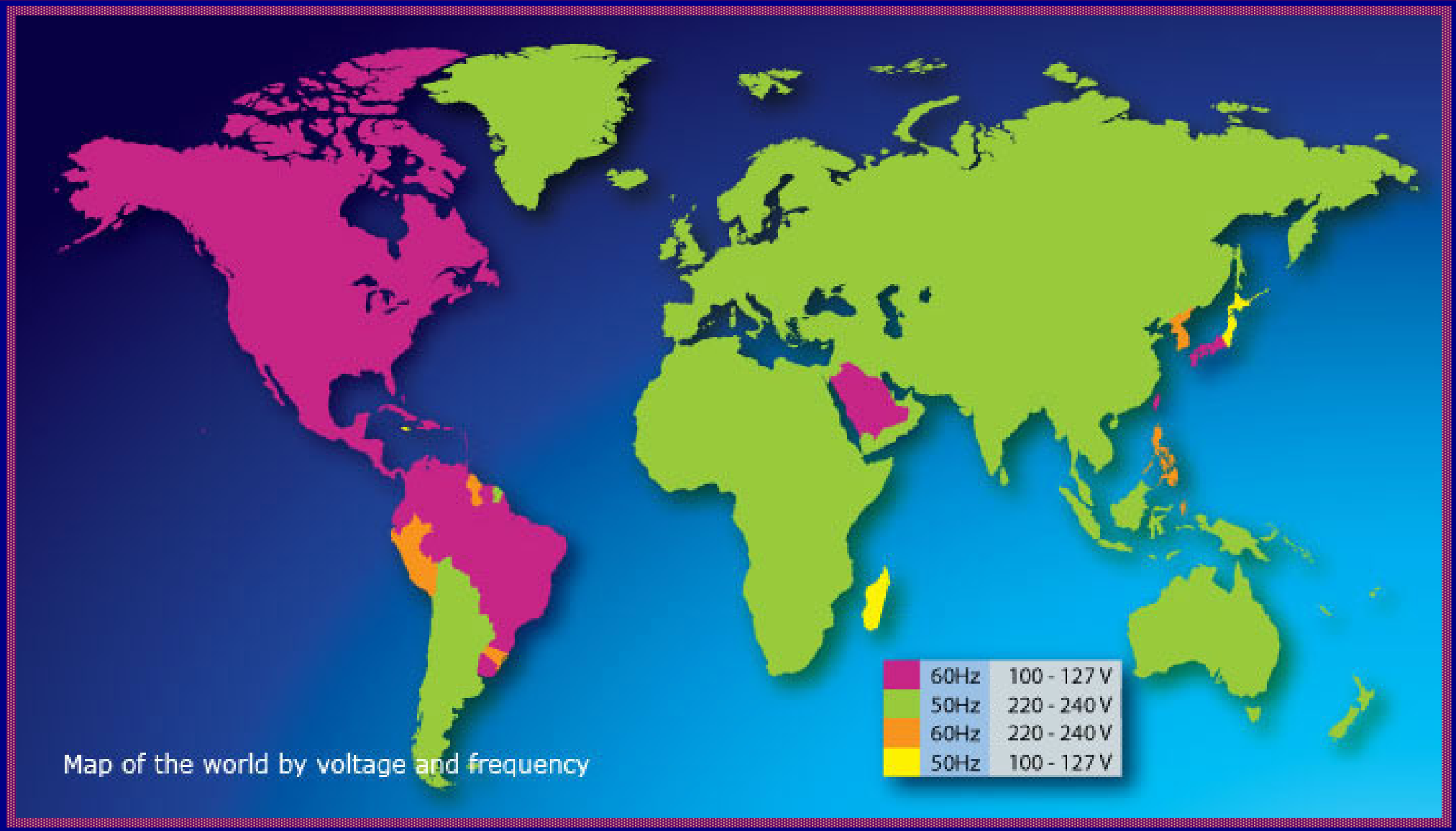
Worldwide Main Voltage & Frequency



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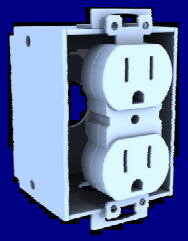
From Light Bulb to LED

Conventional Lighting

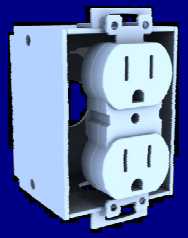


AC Electricity

Switch / Dimmer

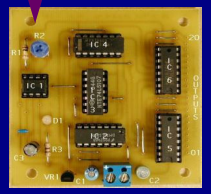
Bulb / Lamp

Conventional DCLED lighting



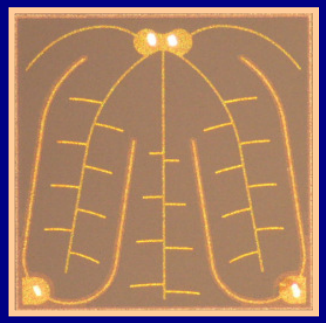
AC Electricity

$$ ↑ & η ↓

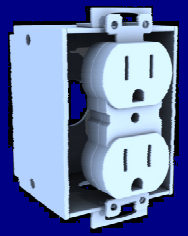


Converter / Adapter

Control circuit



LED driven via DC



AC Electricity

Switch / Dimmer

LED via AC

B

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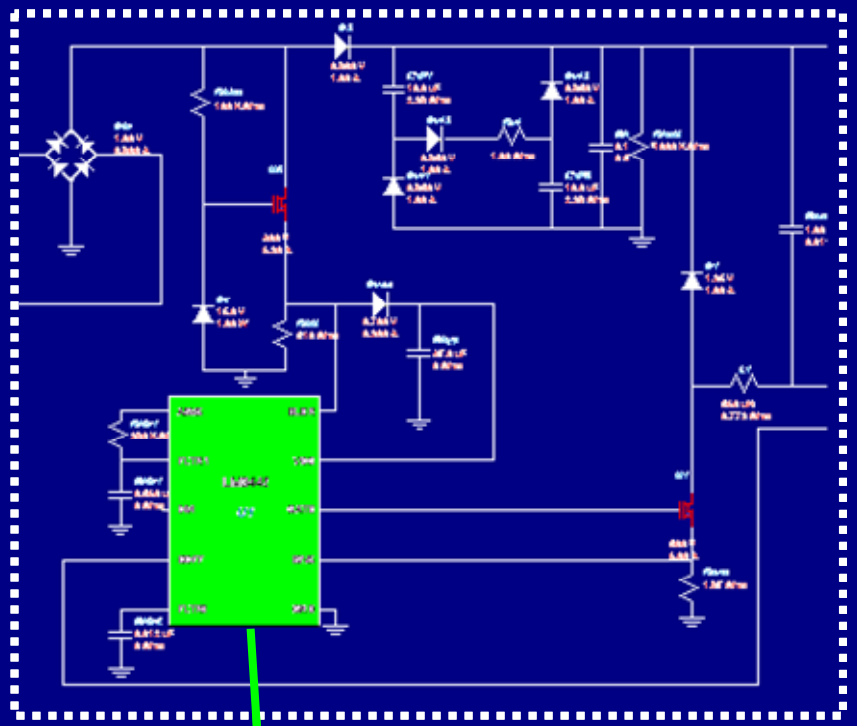
Efficiency from AC Utility to DC Input

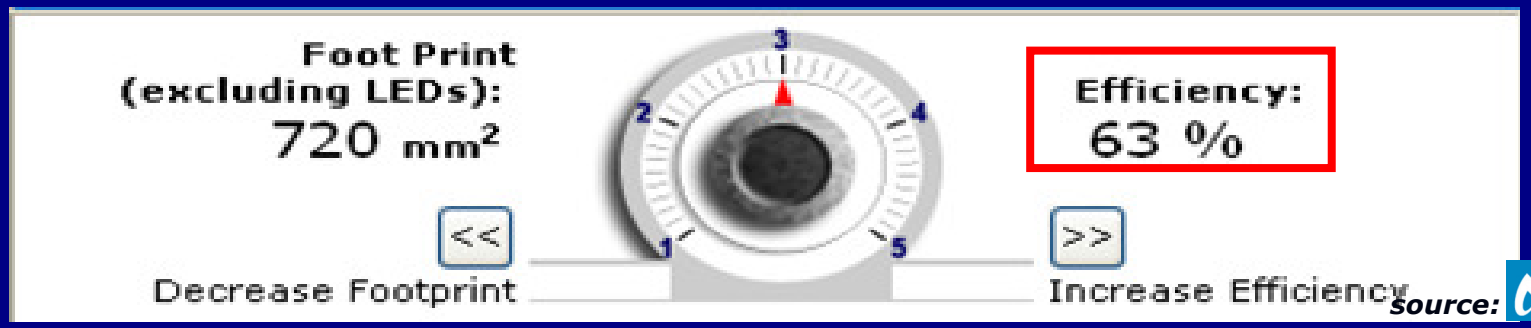
AC 110~130V



LUXEON® Rebels × 2

DC V: 7.6V
I: 350mA

Driver IC LM3445



source: National Semiconductor

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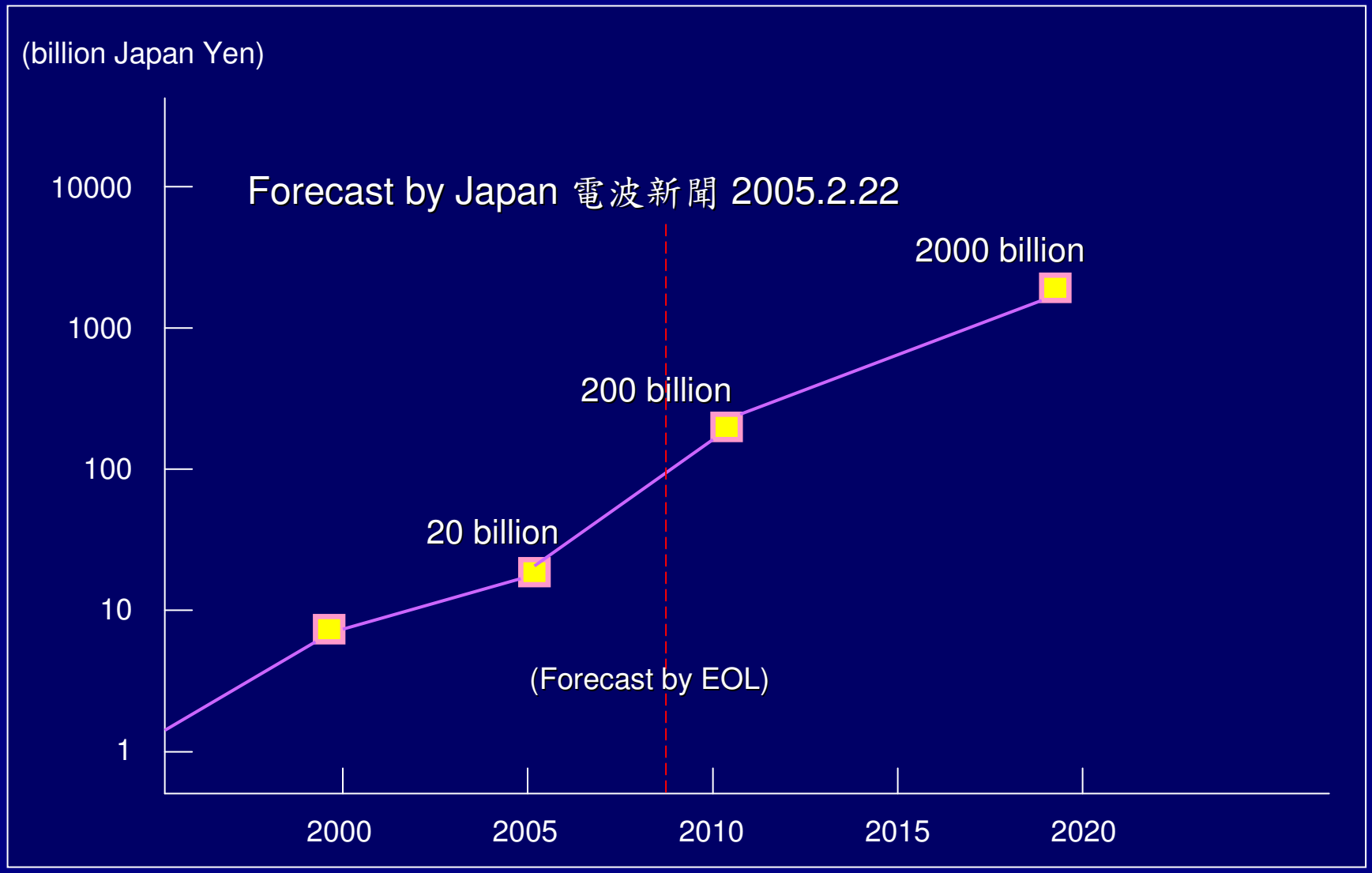
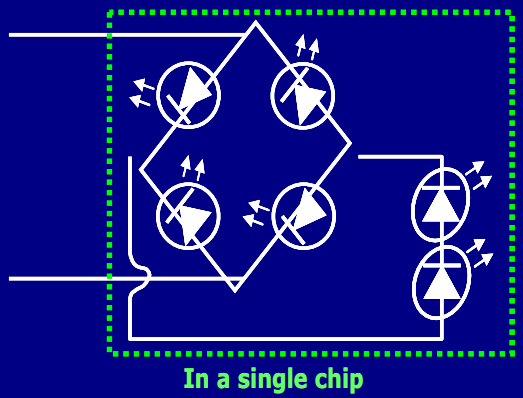
The ACLED Market Forecast

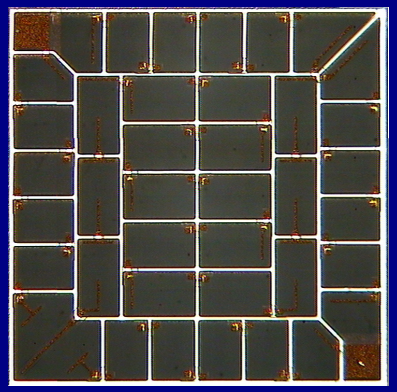


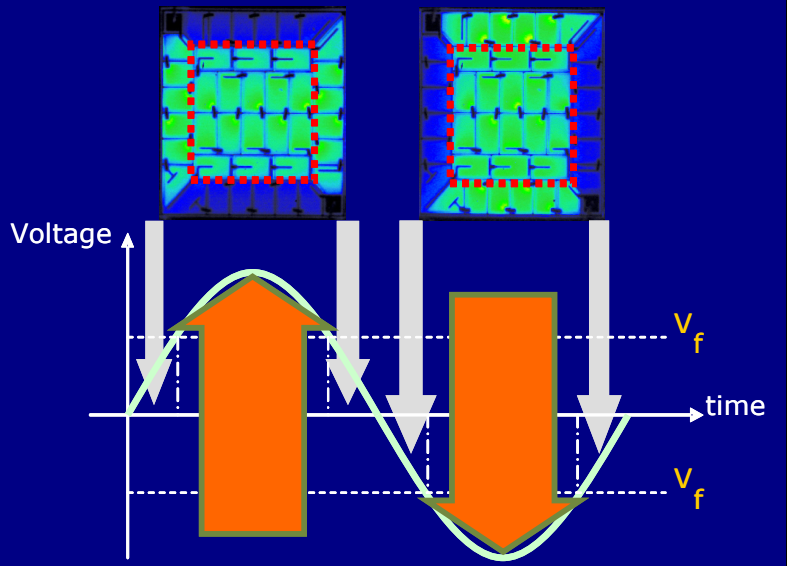
Innovation for LED Lighting: ACLED

ACLED **Circuit**



chip design



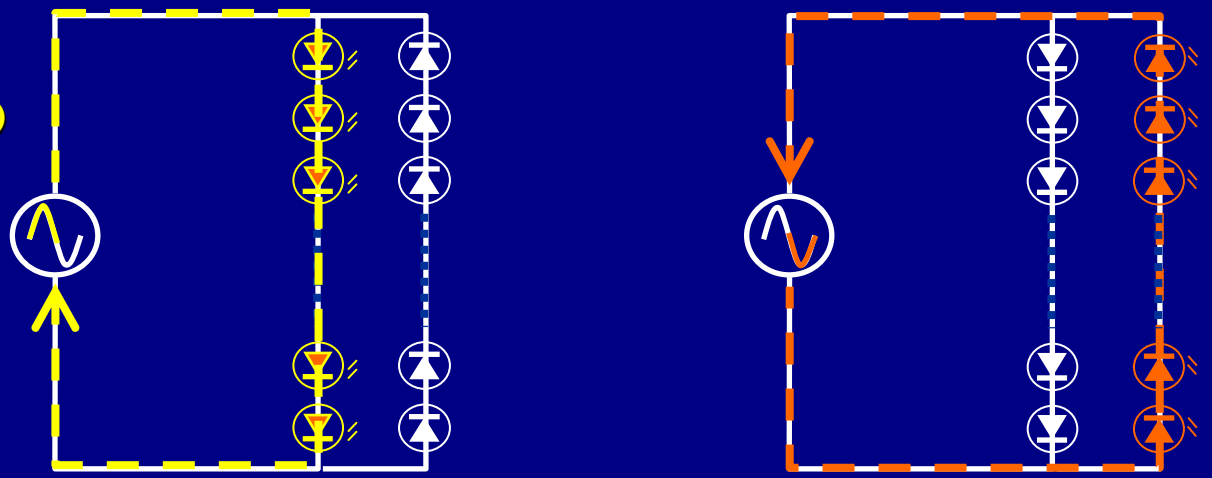


- ***AC LED chip works under high voltage driven directly.***
- ***No additional rectifier or adapter need.***
- ***The area size and the numbers of microchips (cells) decide the driving voltage and power.***

Principles Behind AC-Driven LED

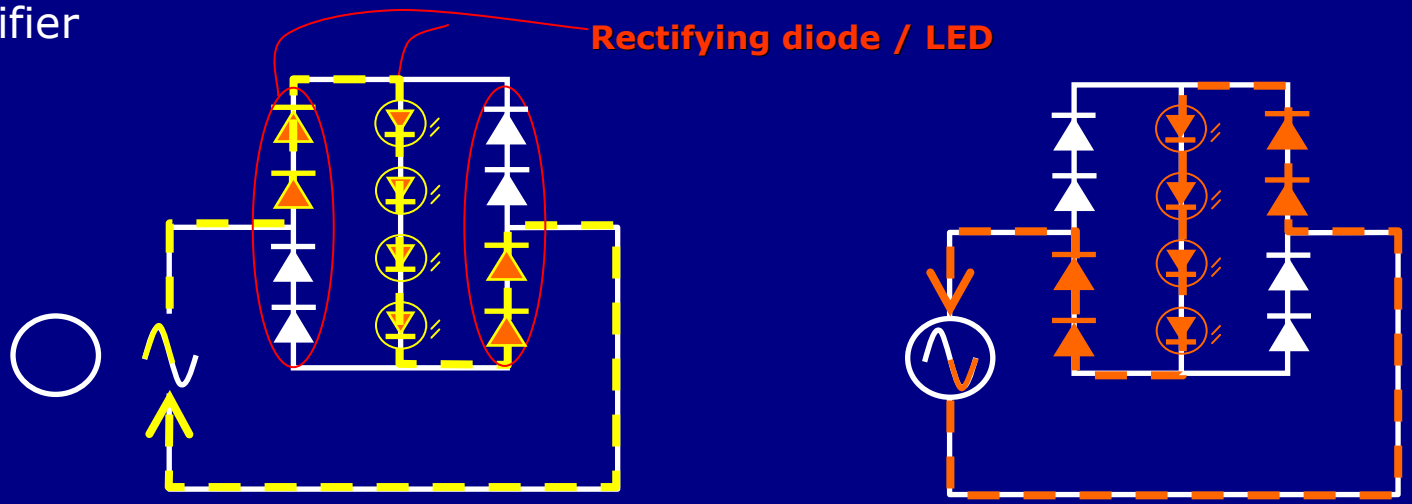
- **Circuit Layout**
  - Diode Rectifier

(Seoul Semiconductor)



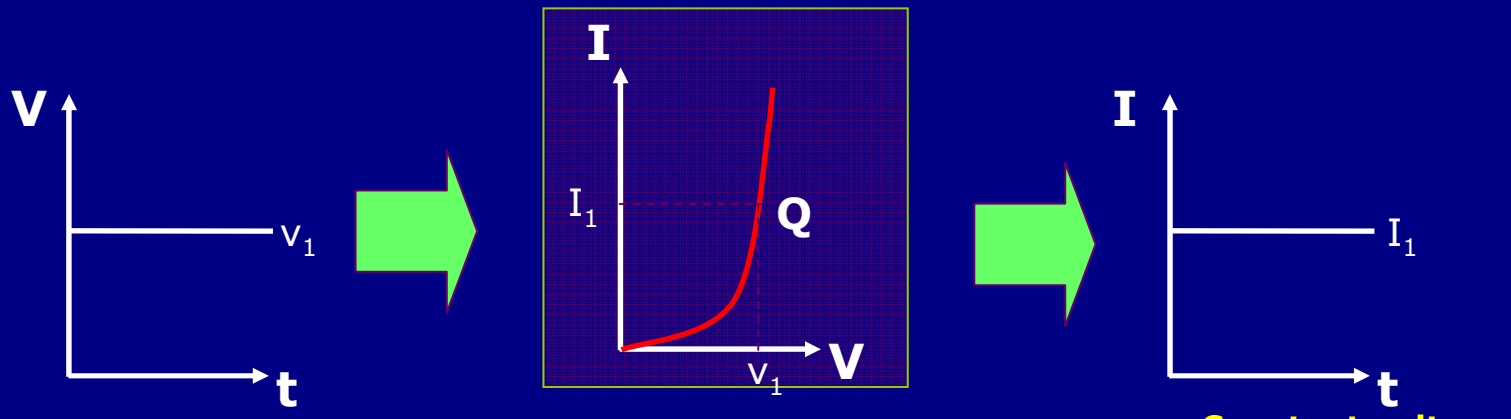
  - Bridge Rectifier

(ITRI, Epistar)



Principles Behind AC-Driven LED

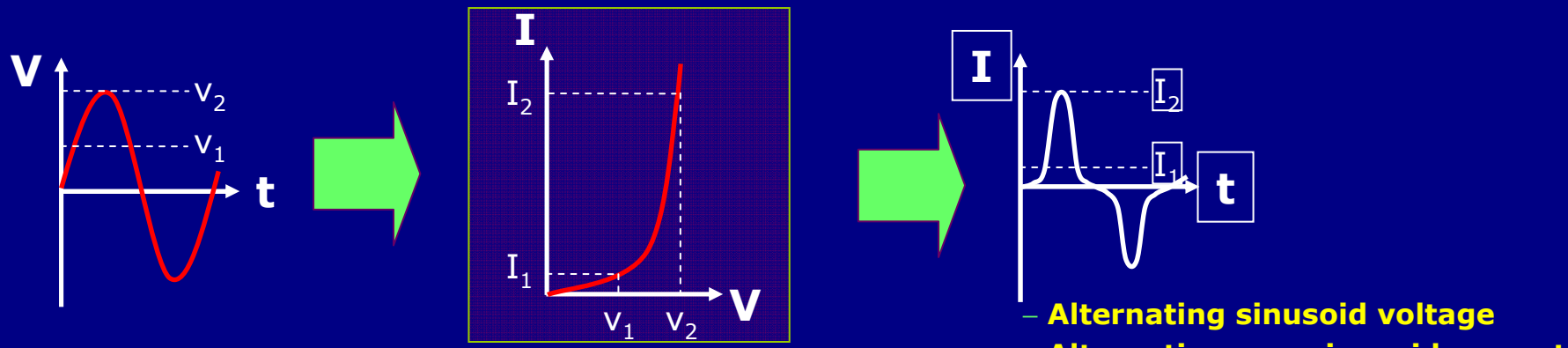
- **Operation Point for DCLED is static**



i-v transfer function of diode

- Constant voltage
- Constant current

- **Operation Point for ACLED is dynamic**

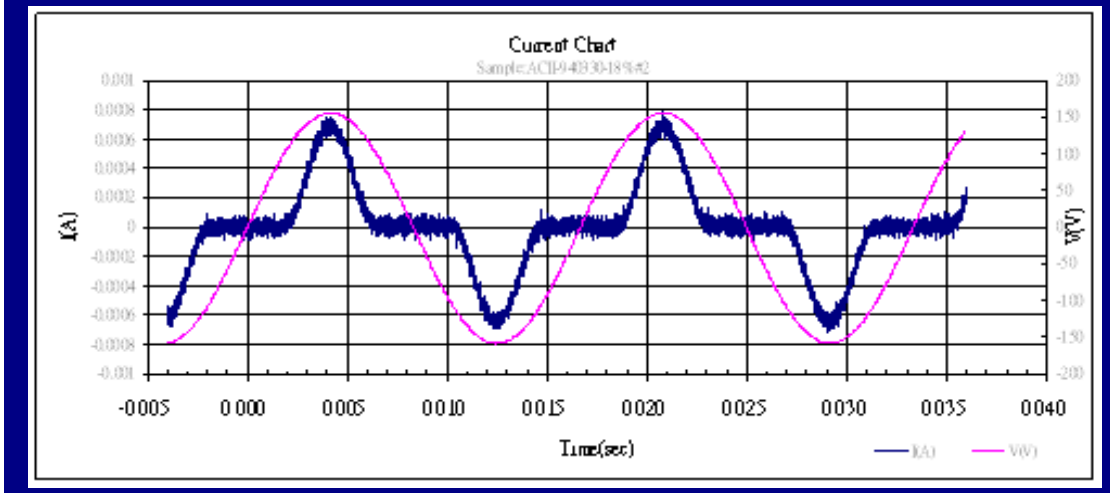


i-v transfer function of diode

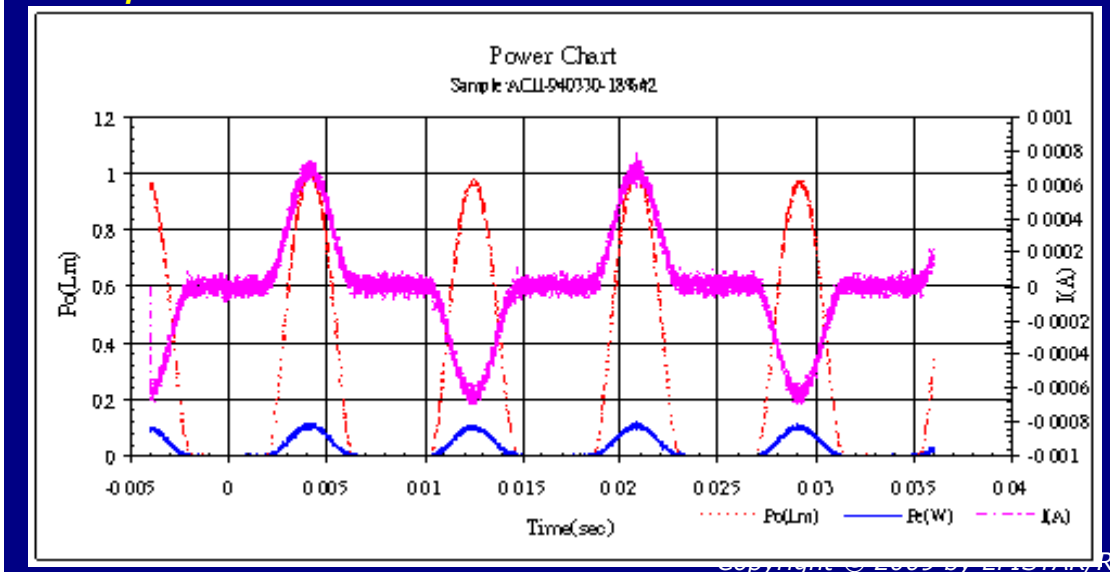
- Alternating sinusoid voltage
- Alternating non-sinusoid current

Principle Behind AC-Driven LED

– *I-V Characteristics of AC LED*



– *$P_{optical}$ & $P_{electric}$-I Characteristics of AC LED*



- **Power Factor**
  - ***Real Power:***

$$P_{real} = \frac{1}{T}\int_0^T V(t)I(t)dt$$

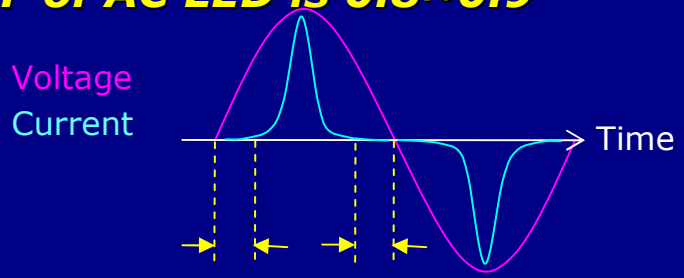
  - ***Apparent power:***

$$P_{apparent} = V_{rms} \times I_{rms}$$

  - ***Power factor is the ratio of the real power to apparent power:***

$$P.F. = \frac{P_{real}}{P_{apparent}}$$

The PF of AC LED is 0.8~0.9



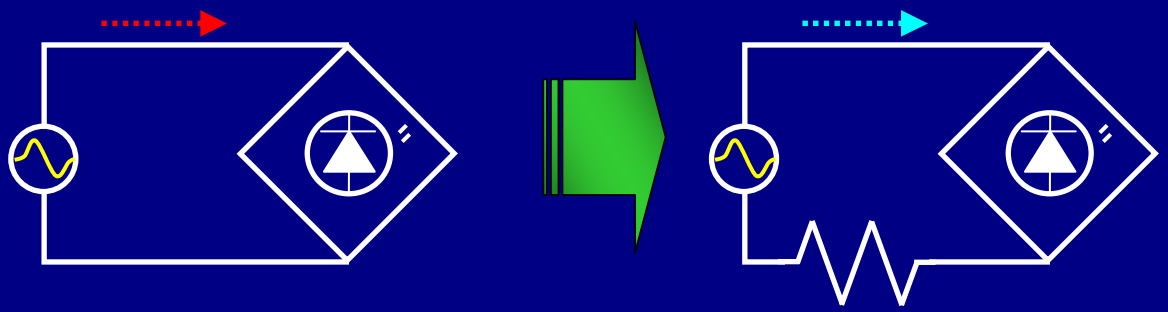
How to increase the PF ??

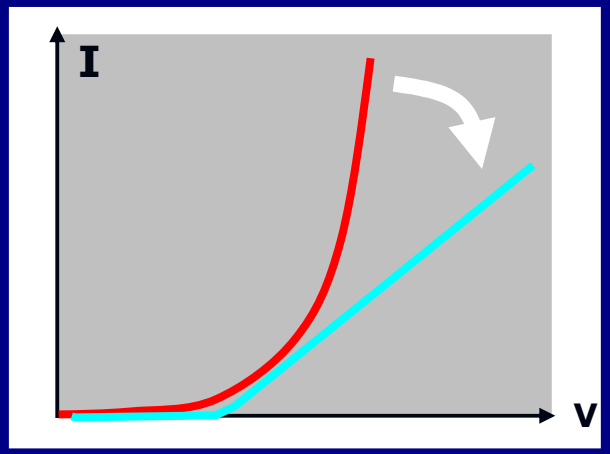
1. Increase the cell number
2. Reduce the operation current
3. Add resistor

Solutions for Power System Variations

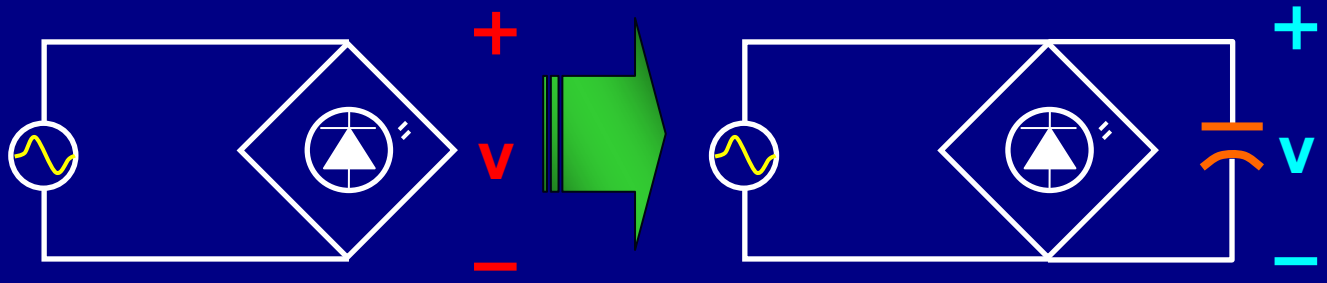
- **Adding a resistor**

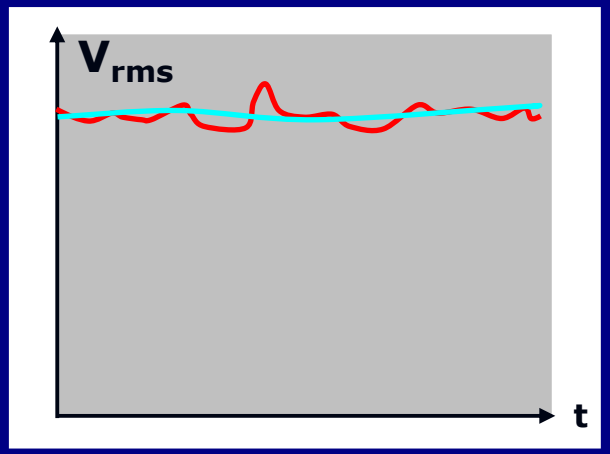
$I \propto \exp\{V\}$ $I \propto V$





- **Adding a Capacitor**





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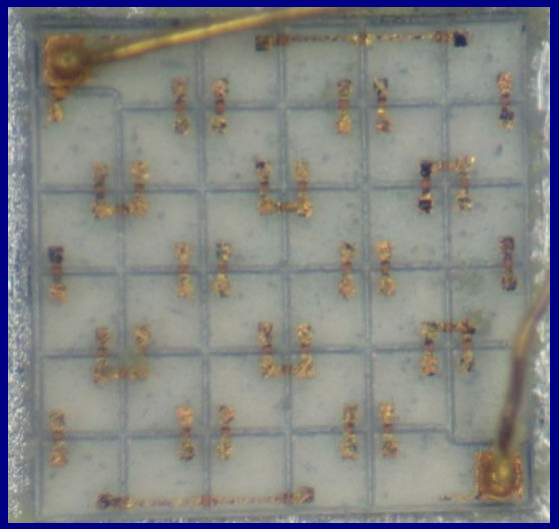
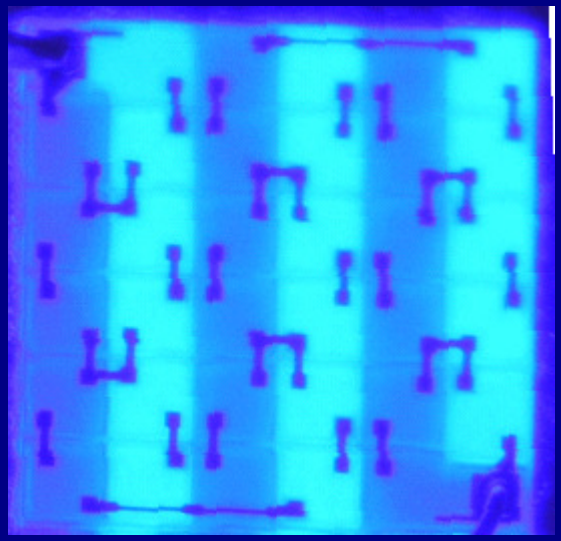
Seoul Semiconductor ACLED

- 外觀

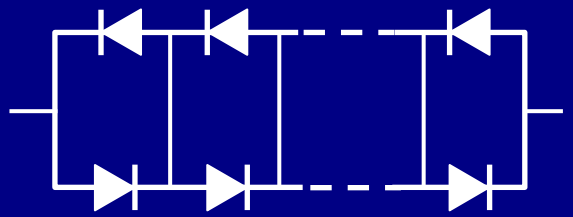


- DC下的近場



- 等效電路

(Diode rectifier type)



- 優點
  - 每一顆逆向LED所承受的逆向偏壓是一樣的
  - 不需考慮恆時發亮區及整流區的面積比例問題，設計較爲單純

ACLED Chip Performances

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(Customer Packaging Data)

Product Type:

ES-RD-AC110V-A55-28L-3 (Bin 03)

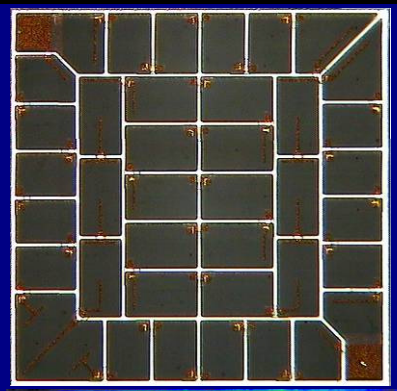
Vf @ 10mA (without resistor): ~ 90 V

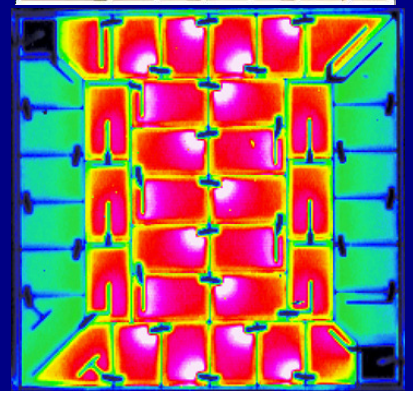
Wld: 455.0 ~ 460.0 nm

PS : 1. LITEON
2. No Resistor
3. η is estimated

Name	X	Y	Lumen	CCT	I	V	Efficiency
No./Unit			lm	K	Irms	Vrms	lm/W
Min	**0.357**	**0.414**	**56.29**	**4575**	**10.0**	**92.0**	**68.0**
Max	**0.369**	**0.430**	**62.67**	**4828**	**10.0**	**94.0**	**74.1**
Avg.	**0.363**	**0.422**	**59.37**	**4692**	**10.0**	**93.3**	**70.7**
StdDev	**0.006**	**0.008**	**3.48**	**112**	**0.0**	**0.9**	

ES-RD-AC110V-A55-28L	
Driving Voltage : 110V (rms)	
Driving Current : 12mA (rms)	
Bin	Resister (Ω) ± 80 (Ω)
01	1385
02	1230
03	1075
04	920
05	765
06	610
07	455
08	300





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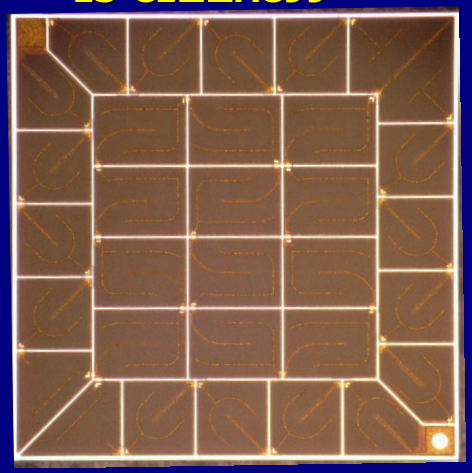
ACLED Family

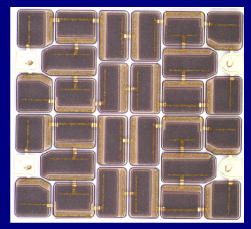
Power Consumption

ES-CE□□AC99



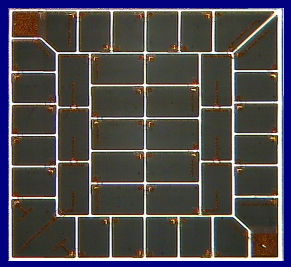
110V /55mA @ 4W

ES-CE□□AE47



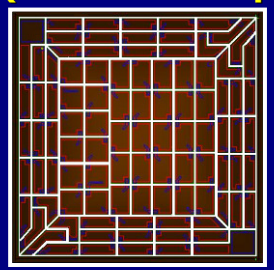
32V /30mA @ 0.7W

ES-CE□□AC55



110V / 12mA @1W

ES-CE□□AD55 (under develop)



220V /6mA @ 1W

Driving Voltage

Lower Cost Approach: ACLED

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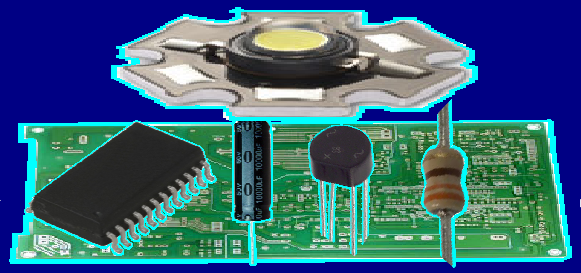
EPI

DCLED

USD$0.6~1.0

150 lm/w
@2012 DOE Target



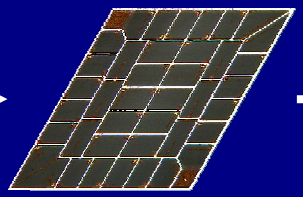
Driver IC USD$ 2.0
Other component USD$ 4.0
MCPCB USD$ 1.0

Efficiency~80%

480 lm @ 4W
⇒ ~47 lm/ USD
(if 4 chip per package)

Package USD$ 0.3
Fixture USD$ 0.5

ACLED



USD$0.9~1.5

130 lm/w
@2012 Target

MCPCB USD$ 1.0

P.F. ~ 95%

490 lm @ 4W
⇒ ~90 lm/ USD
(if 4 chip per package)

Package USD$ 0.3
Fixture USD$ 0.5

Note: The cost of LED chip are only for reference because it depended on performance and chip size.

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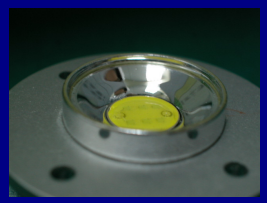
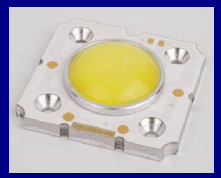
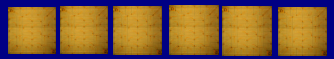
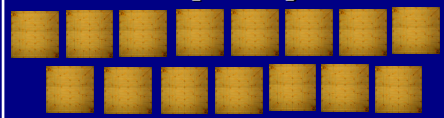
Use AC55 to form Lamps

	4W AC LED	6W AC LED	15W AC LED
Type			
AC LED Module			
LED	AC55 (1W) X 4 	AC55 (1W) X 6 	AC55 (1W) X 15 
Luminous Flux @ 5700K	230 lm	350 lm	900 lm
Luminous Flux @ 3000K	160 lm	250 lm	650 lm

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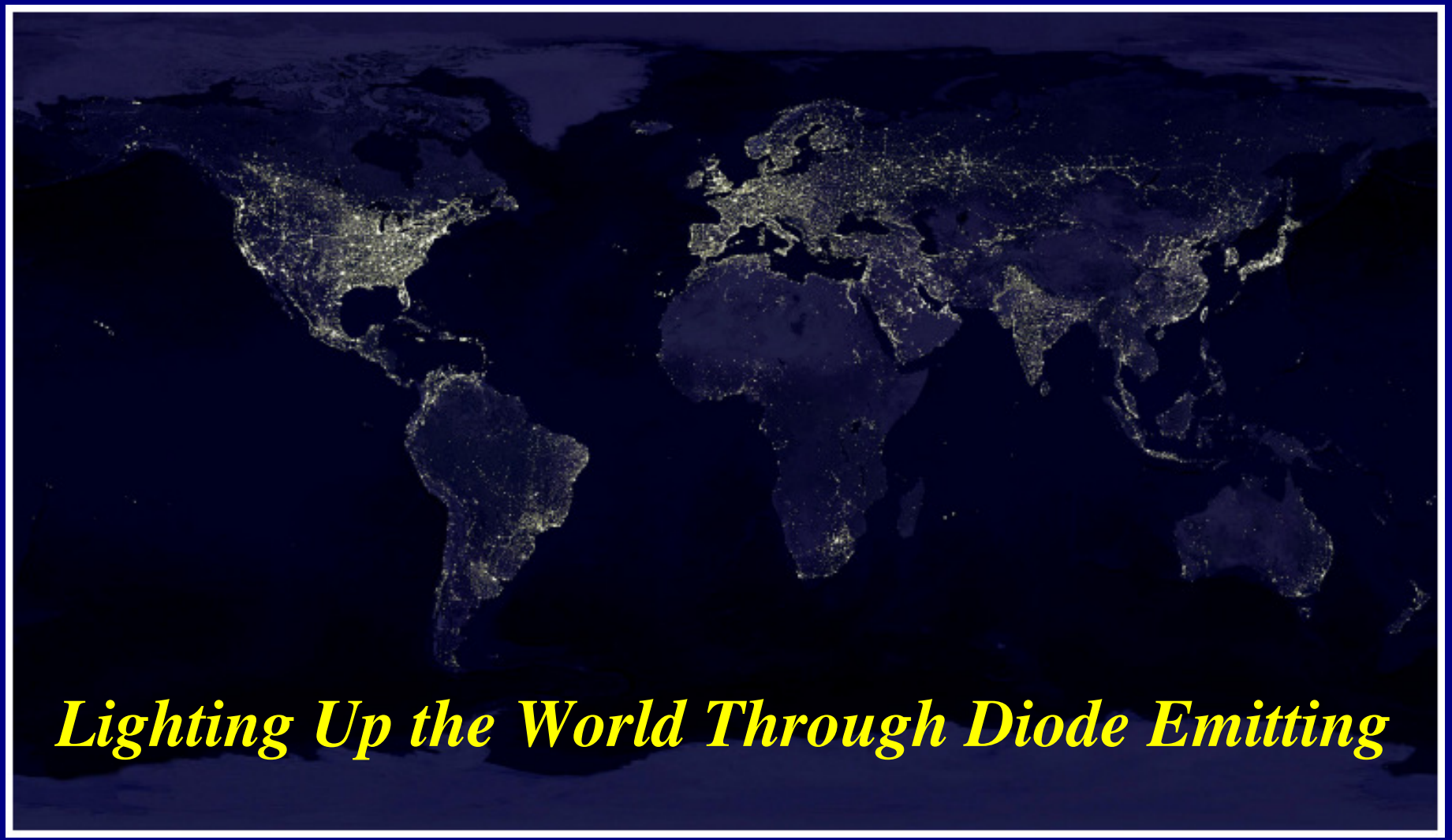
Vision With LED



Photograph: NASA