High Power LED for Solid-state Lighting

SJ Hon

2009.07.13

Motivation

Lighting consumes 22 % of electricity

8 % of total energy

(statistics of USA)

Solid State Lighting, by 2025

50% reduction of energy consumed by lighting

10% reduction in greenhouse gas emissions

Customer savings of ***$30 billion annually***

(U.S. Dep. Energy)

Outline

- Market Trends for HB-LED and Lighting
- Technical Trends & Challenges for LED Lighting
- AC LED for Lighting
- Summary

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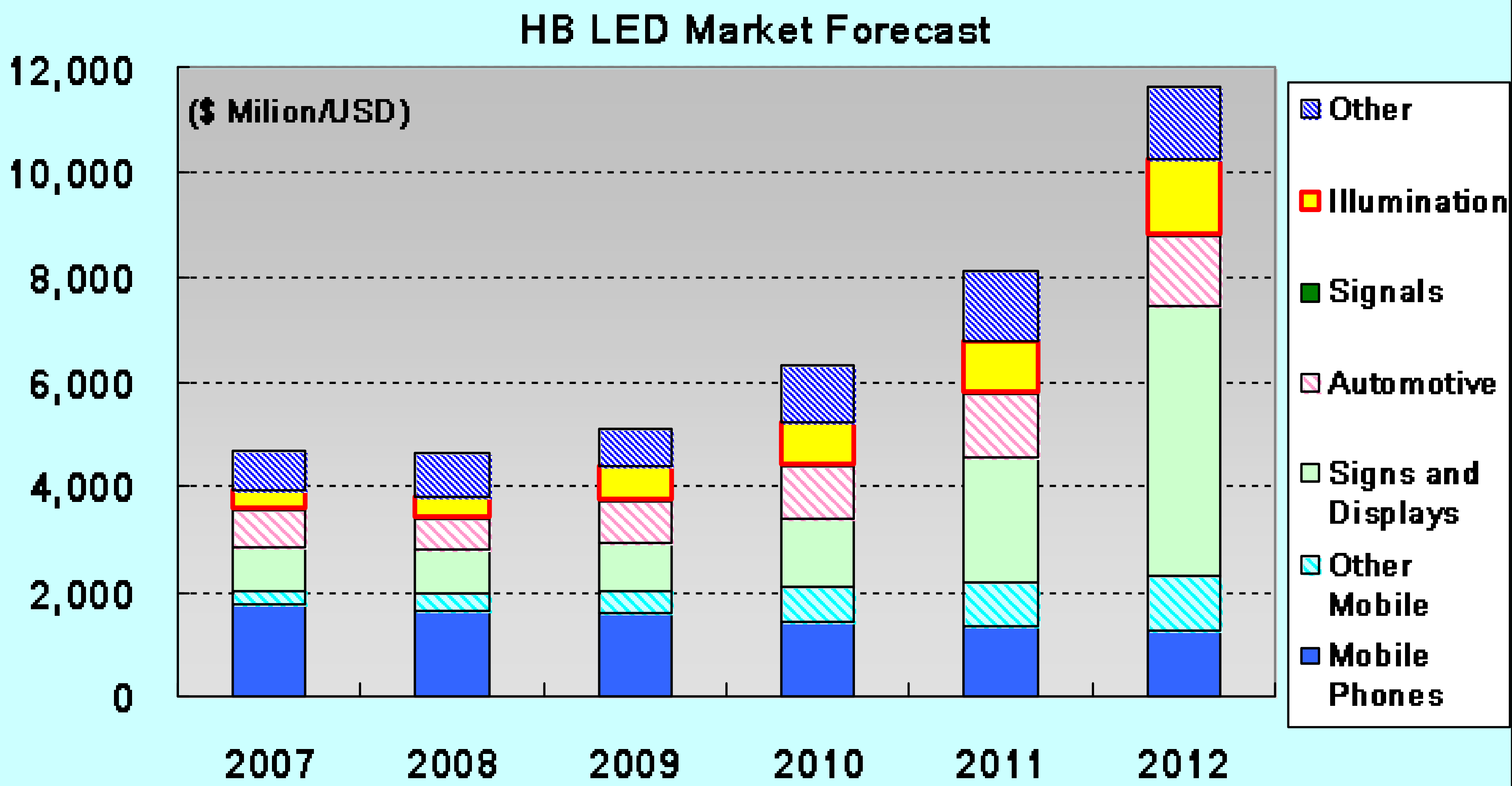
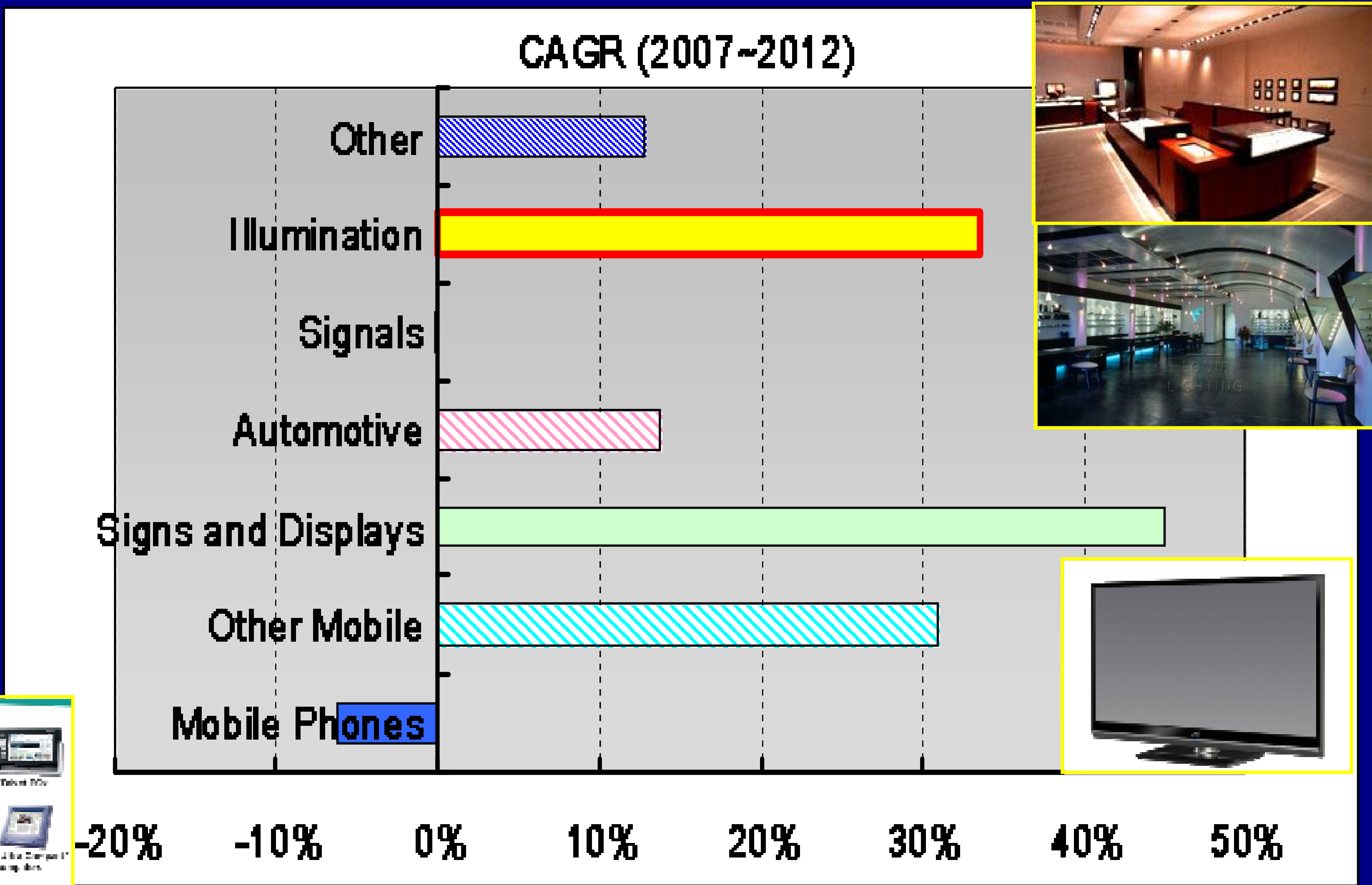
Global HB LED Market Forecast



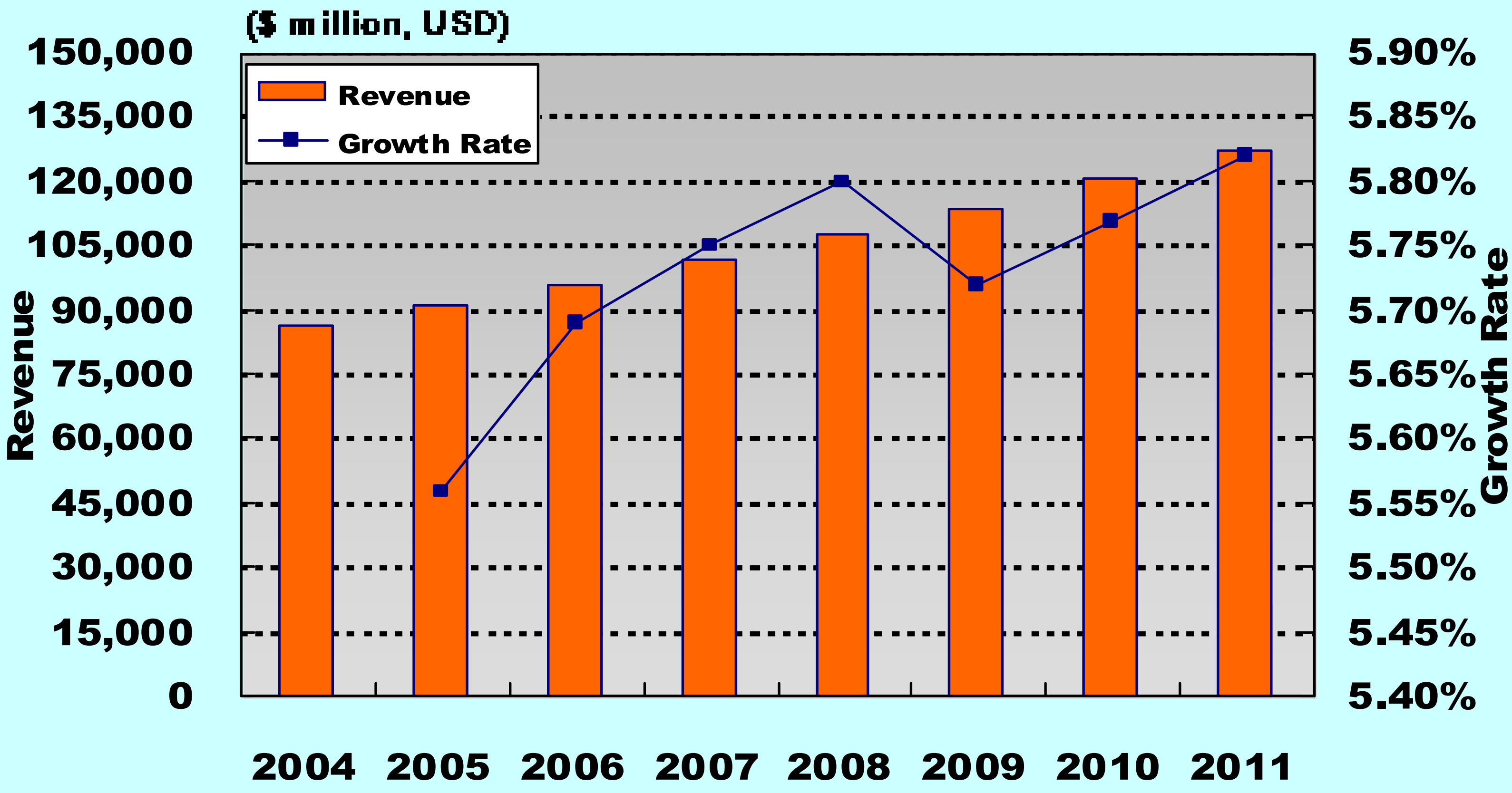
Source : Strategies Unlimited

CAGR by HB LED Application



Source : Strategies Unlimited

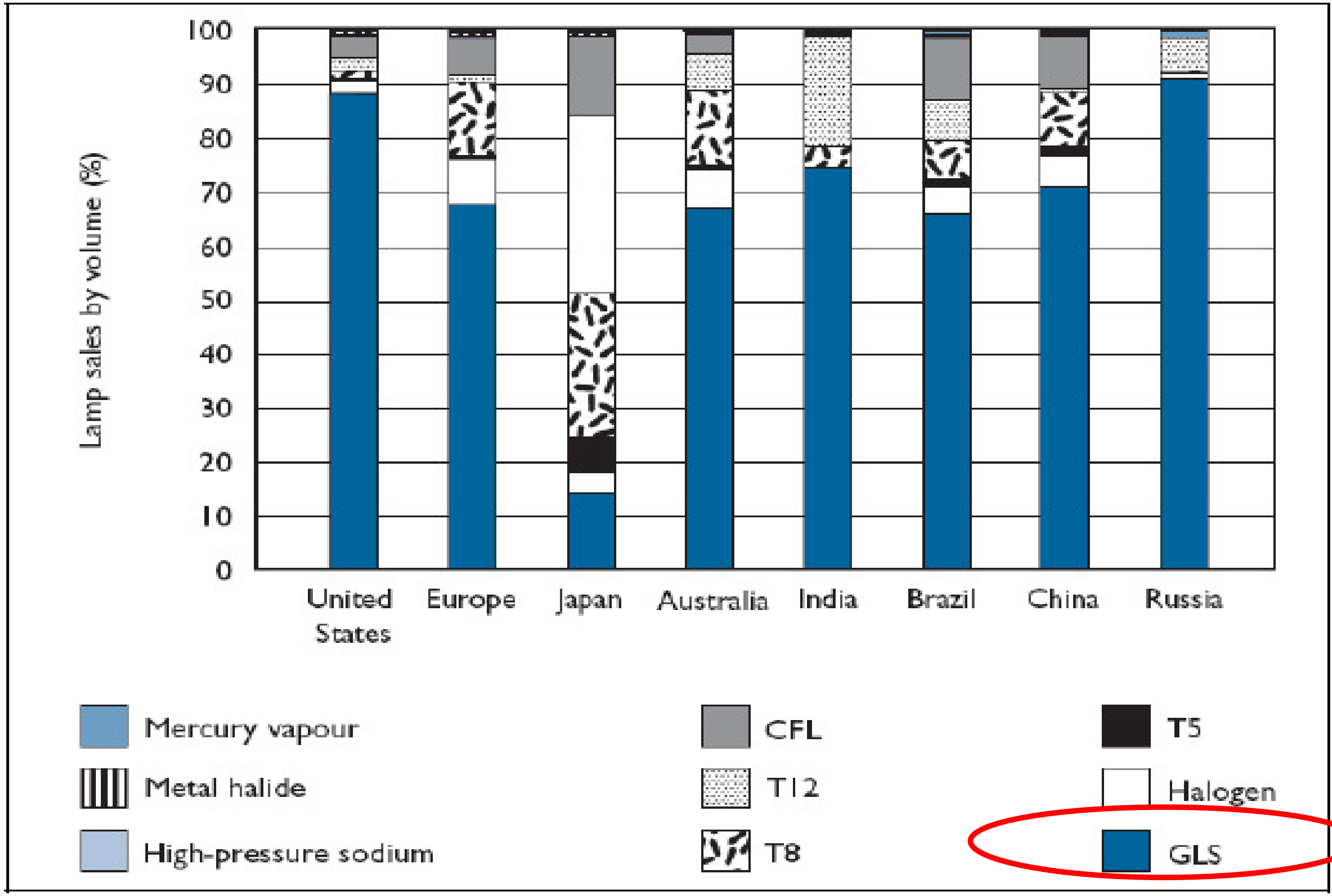
Global Lighting Market Forecast



Source : Freedona, World lighting Fixture (summarized by DIGITIMES, 2008/12)

- Revenue will be ~120, 000 Million USD in 2010.
- Market size is about 10 time larger than HB-LED’s

Lighting Market by Region









資料來源：IEA(2006)

全球主要區域電光源銷售比重

Incandescent still dominates!

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Phase-out of incandescent light bulbs

Region	Country	Year '09	'10	'11	'12	'13	'14	'15	'16	'17	'18	Description
Asia	Australia											the Australian Federal Government announced that by 2010, incandescent light bulbs would be banned
	NZ											will be doing something very similar as Australia
	Philippines											Once put in effect, the country will be the first in Asia to ban incandescent bulbs
	Indonia											arrange 50 million pcs of energy saver bulbs at lowest possible price
	Pakistan											arrange 10 million pcs of energy saver bulbs at lowest possible price
	Japan											ban to use incandescent bulb from 2012
	Taiwan											ban to produce incandescent bulb
Europe	Ireland											proposes to ban traditional incandescent light bulbs in January 2009
	UK											plans to phase out the sale of incandescent light bulbs by 2011 ' retailers will voluntarily decline to stock 150 watt bulbs from January 2008, 100 watt bulbs from January 2009, 40 watt bulbs in 2010, and all remaining bulbs by 2011
	Holand											wants a ban on incandescent light bulbs within 4 years
	Finland											banning incandescent light bulbs in Finland by 2011
	Italy											banning incandescent light bulbs in Italy by 2010
	Belgium											intent on banning incandescent light bulbs
	EU											proposed a ban on incandescent light bulbs, planned to come into effect in the near future, but this will not affect existing incandescent bulbs, only the production of new bulbs
North America	Canada											The plan would ban the sale of incandescent light bulbs, but not their use
	United States											banned (by January 2014) incandescent bulbs that produce 310 - 2600 lumens of light. Bulbs outside this range (roughly, light bulbs currently less than 40 Watts or more than 150 Watts)
	California											phase out the use of incandescent bulbs by 2018
	New Jersey											switch to fluorescent lighting in government buildings over the next three years
South America	Brazil											attempt to phase out the use of incandescent light bulbs
	Venezuela											attempt to phase out the use of incandescent light bulbs.

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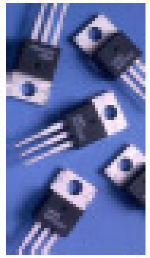
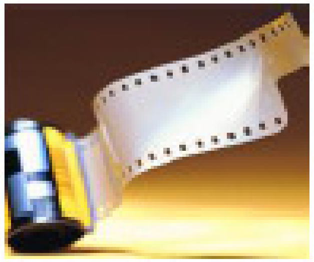
History of Success for Solid State Technology

Vacuum Tubes → Transistors (1940s – 1950s)



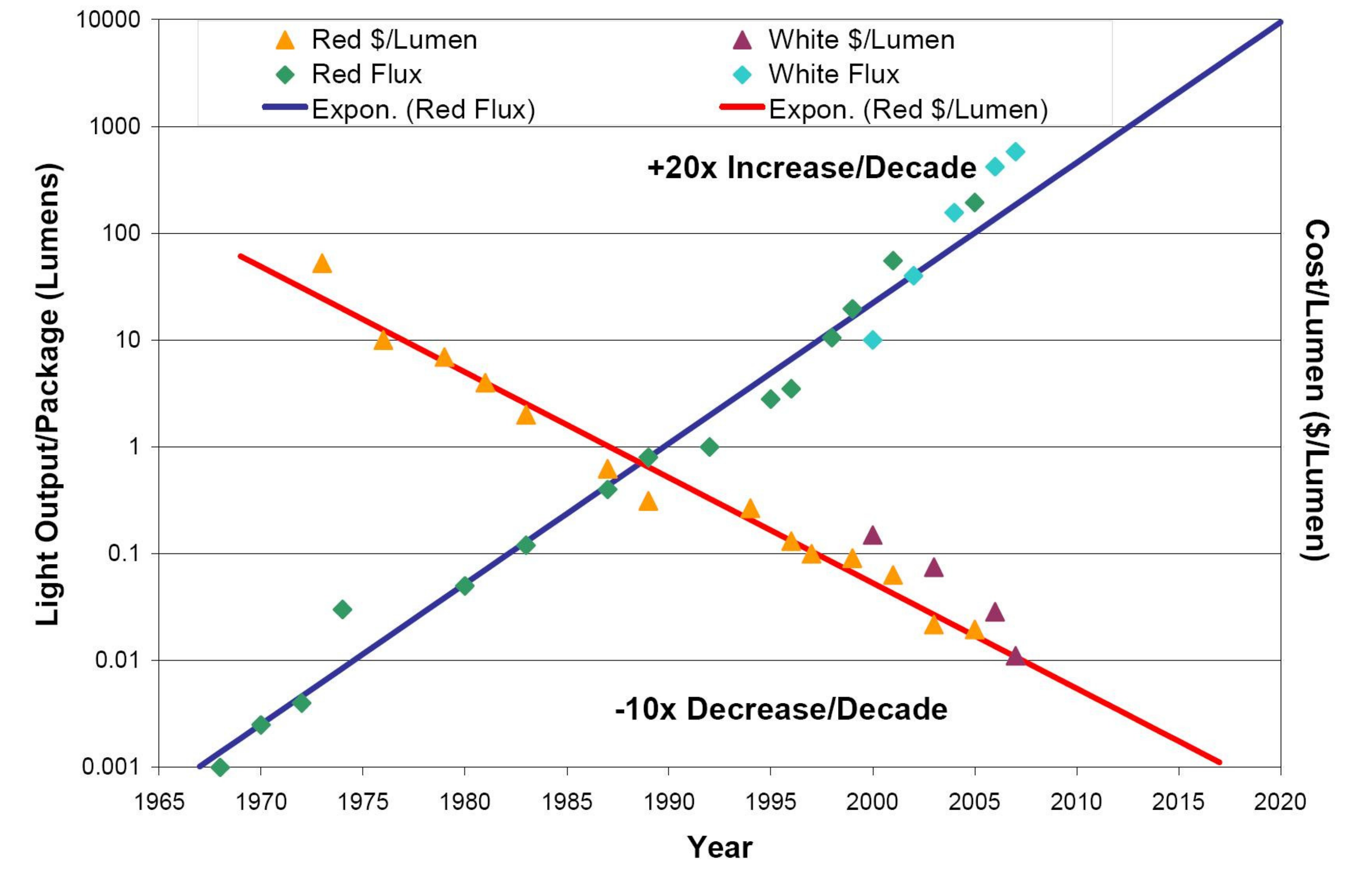
CRT → Flat Panel (1990s – 2000s)



Film → Flash Memory (1990s – 2000s)

Light Bulbs/ Fluorescent → Solid State Lighting (2000s – …)

Haitz's Law



Red $/Lumen
White $/Lumen
Red Flux
White Flux
Expon. (Red Flux)
Expon. (Red $/Lumen)
+20x Increase/Decade
-10x Decrease/Decade
Light Output/Package (Lumens)
Cost/Lumen ($/Lumen)
Year
10000
1000
100
10
1
0.1
0.01
0.001
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020

OIDA Roadmap 2009

Table 4.3.2: Summary of LED Package Performance Projections

Metric	2008	2010	2012	2015
Efficacy- Lab (lm/W)	144	160	176	200
Efficacy- Commercial Cool White (lm/W)	108	147	164	188
Efficacy- Commercial Warm White (lm/W)	64	97	114	138
OEM Lamp ($/klm)	169	101	61	28

Note:

1. Efficacy projections for cool-white packages assume CRI=70 → 80 and a CCT = 4100-6500°K, while efficacy projections for warm-white packages assume CRI =>85 and a CCT of 2800-3500°K. All efficacy projections assume that packages are measured at 25°C.
2. All packages are assumed to have a 350 mA drive current, 1mm^2 die size, package-level specification only (driver/fixture not included), and lifetime as stated in table.
3. Price targets assume an integrated LED lamp, "reasonable volumes" (several 1000s), CRI=70 → 80, color temperature = 4100-6500K.
4. Package life is approximately 50,000 hrs assuming 70% lumen maintenance, "1 watt package," and 350 mA drive current.

Source: LED Technical Committee, Fall 2008

OIDA Luminaire Roadmap 2009

Table 4.3.3: Summary of LED Luminaire Performance Projections (at operating temperatures)

Metric	2008	2010	2012	2015
Package Efficacy-Commercial Cool White (lm/W, 25 degrees C)	108	147	164	188
Thermal Efficiency	85%	89%	91%	95%
Efficiency of Driver	85%	87%	89%	92%
Efficiency of Fixture	80%	83%	87%	92%
Resultant luminaire efficiency	58%	64%	70%	80%
Luminaire Efficacy-Commercial Cool White (lm/W)	62	94	115	151

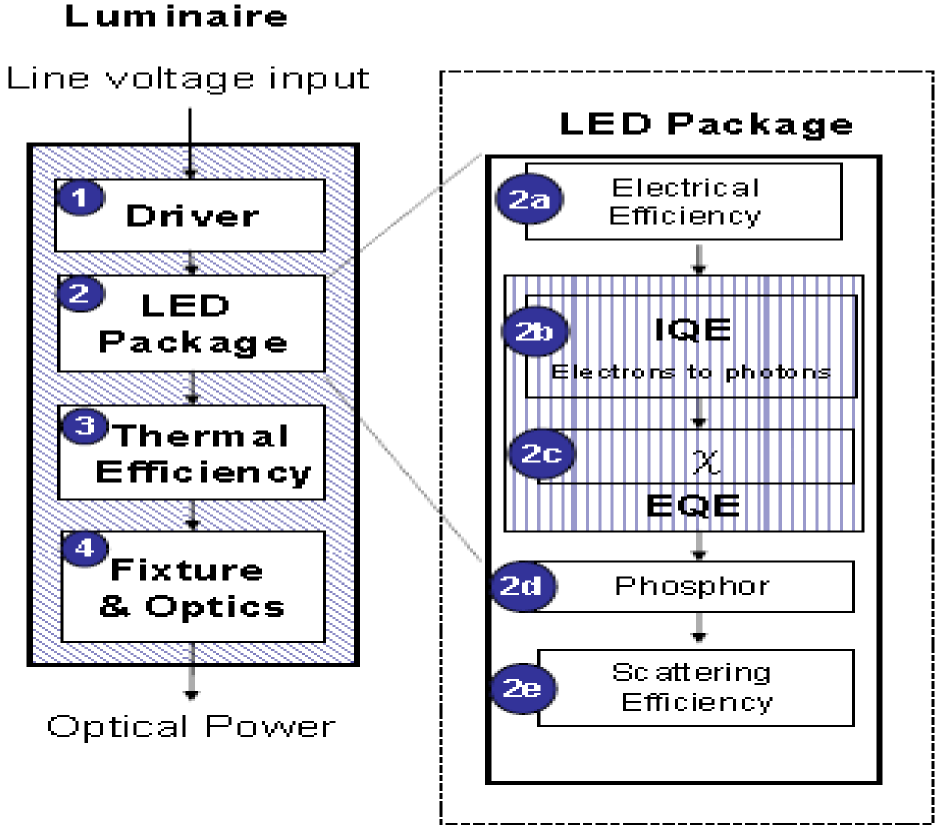
Notes:

1. Efficacy projections for cool-white luminaires assume CRI=70 → 80 and a CCT = 4100-6500°K.
2. All projections assume a 350mA drive current, 1mm^2 die size, reasonable package life and operating temperature.
3. Luminaire efficacies are obtained by multiplying the resultant luminaire efficiency by the package efficacy values.

Source: LED Technical Committee, Fall 2008

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.

Rationale for 200lm/W

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Luminous Efficacy of a Source [lm/W]	=	Luminous Efficacy of Radiation [lm/W]	X	Radiant efficiency
("Wall-plug efficiency")		(Theoretical maximum lm/W)		(External Q.E.)
Luminous flux [lm] / Electrical power [W]		Luminous flux [lm] / Optical power [W]		Optical power [W] / Electrical power [W]

Goal:

200 lm/W		400 lm/W		50 %

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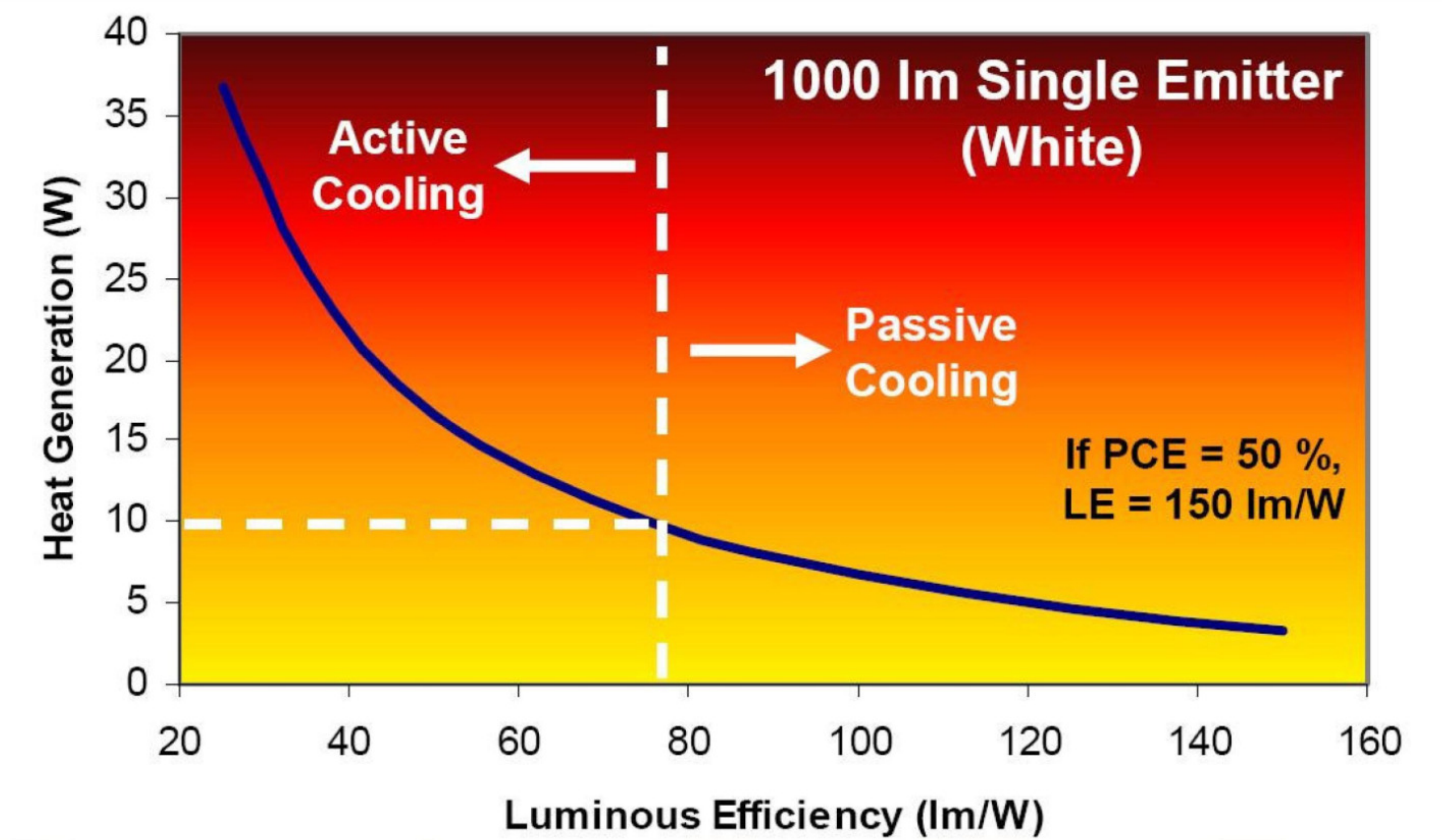
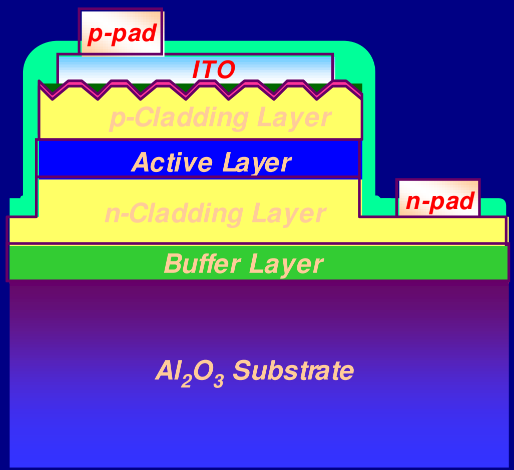
Thermal Issue

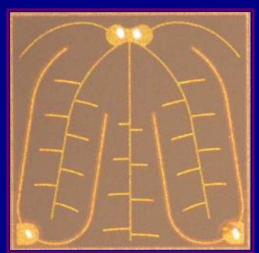


Power Chip Portfolio

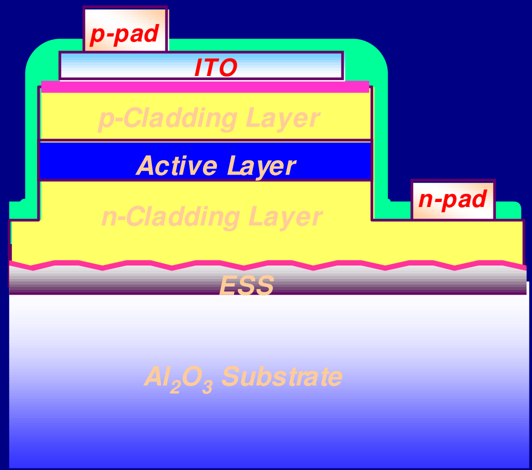
Venus-Series



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

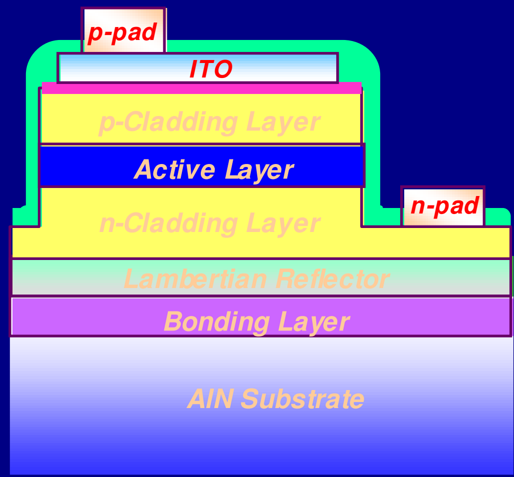


Generic approach



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

Saturn-H Series



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

Power Chip Portfolio

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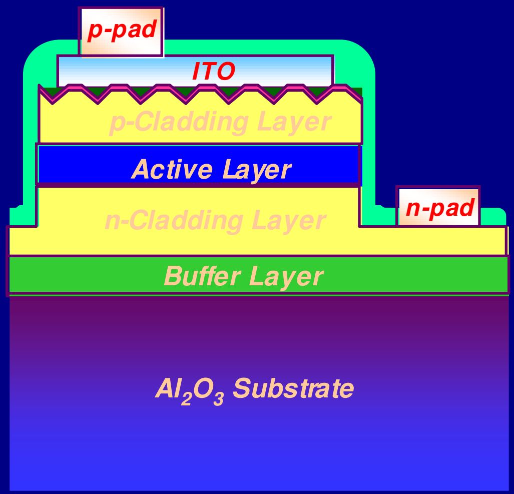
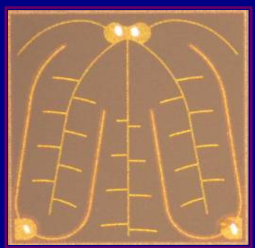
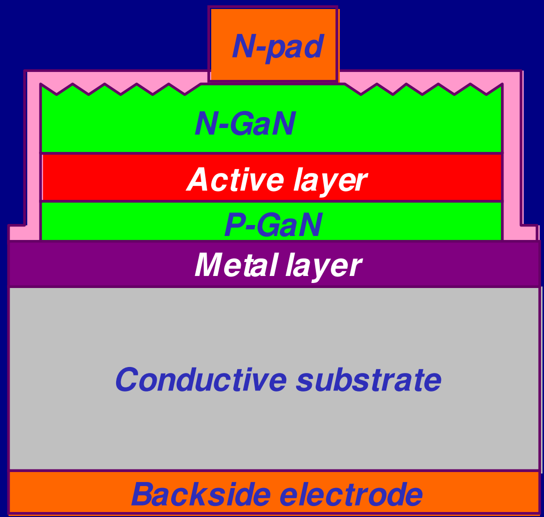
Venus-Series



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

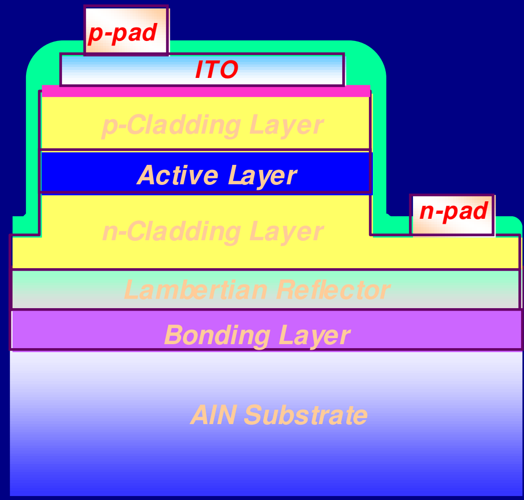


Saturn-N Series



- Flat surface
- Lambertian transmittance
- High $k_{thermal}$ Si substrate
- Narrower view angle
- Eutectic layer

Saturn-H Series



- Advanced Epi structure
- ITO on flat p-GaN
- Lambertian reflector
- High $k_{thermal}$ substrate
- Separation of heat dissipation and current path

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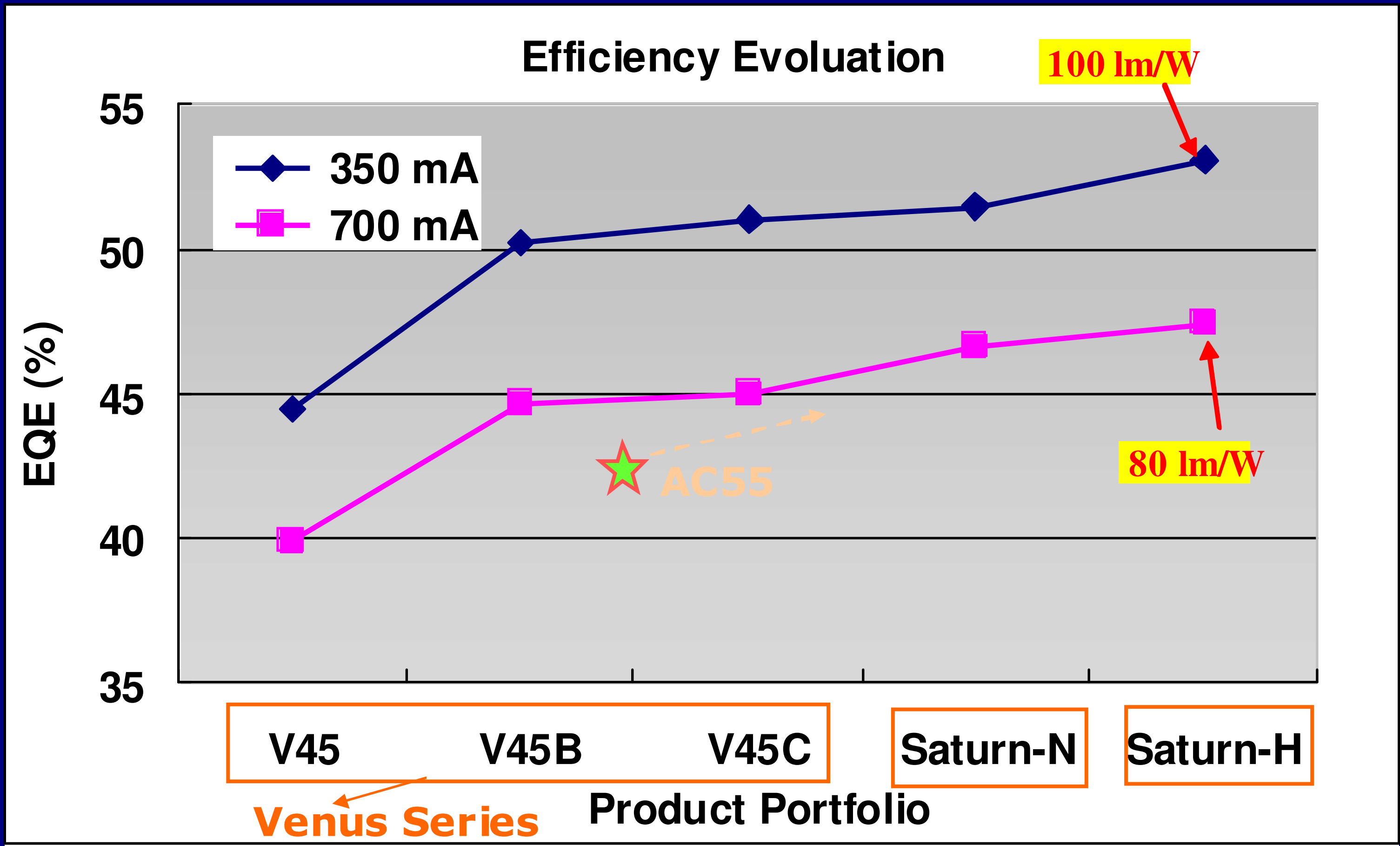
Evolution of Power Chip Performance



- At this moment, only ***Venus*** related technique have been applied to AC LED chip.
- Some advanced techniques for ***Generic*** and ***Saturn*** can be applied to further improving the performance of AC LED in the future

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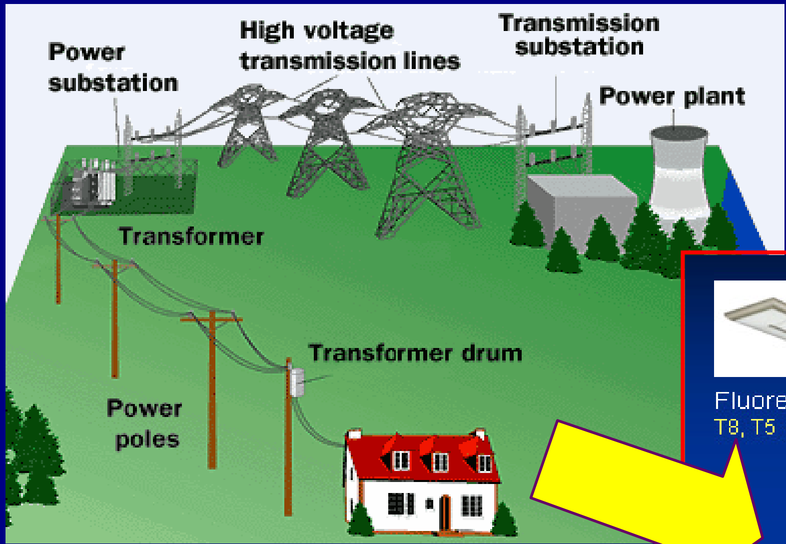
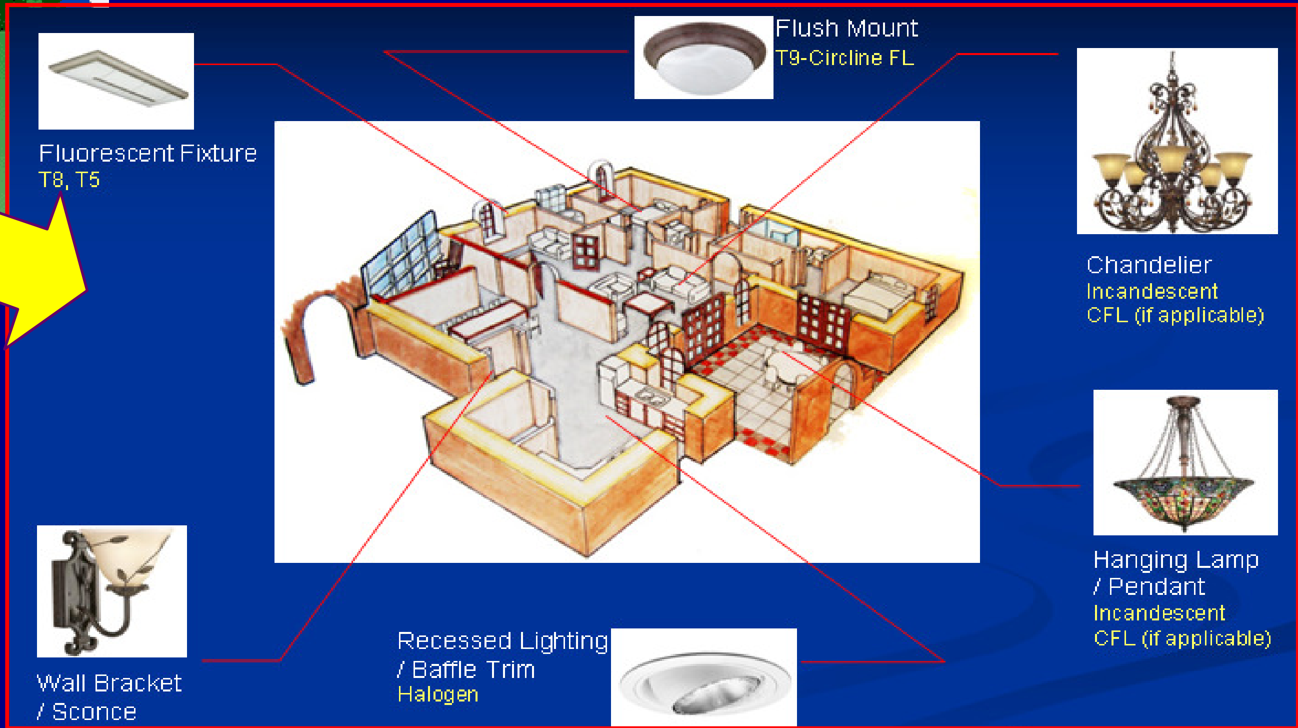
From Power to Illumination



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



AC is everywhere

Worldwide Main Voltage & Frequency

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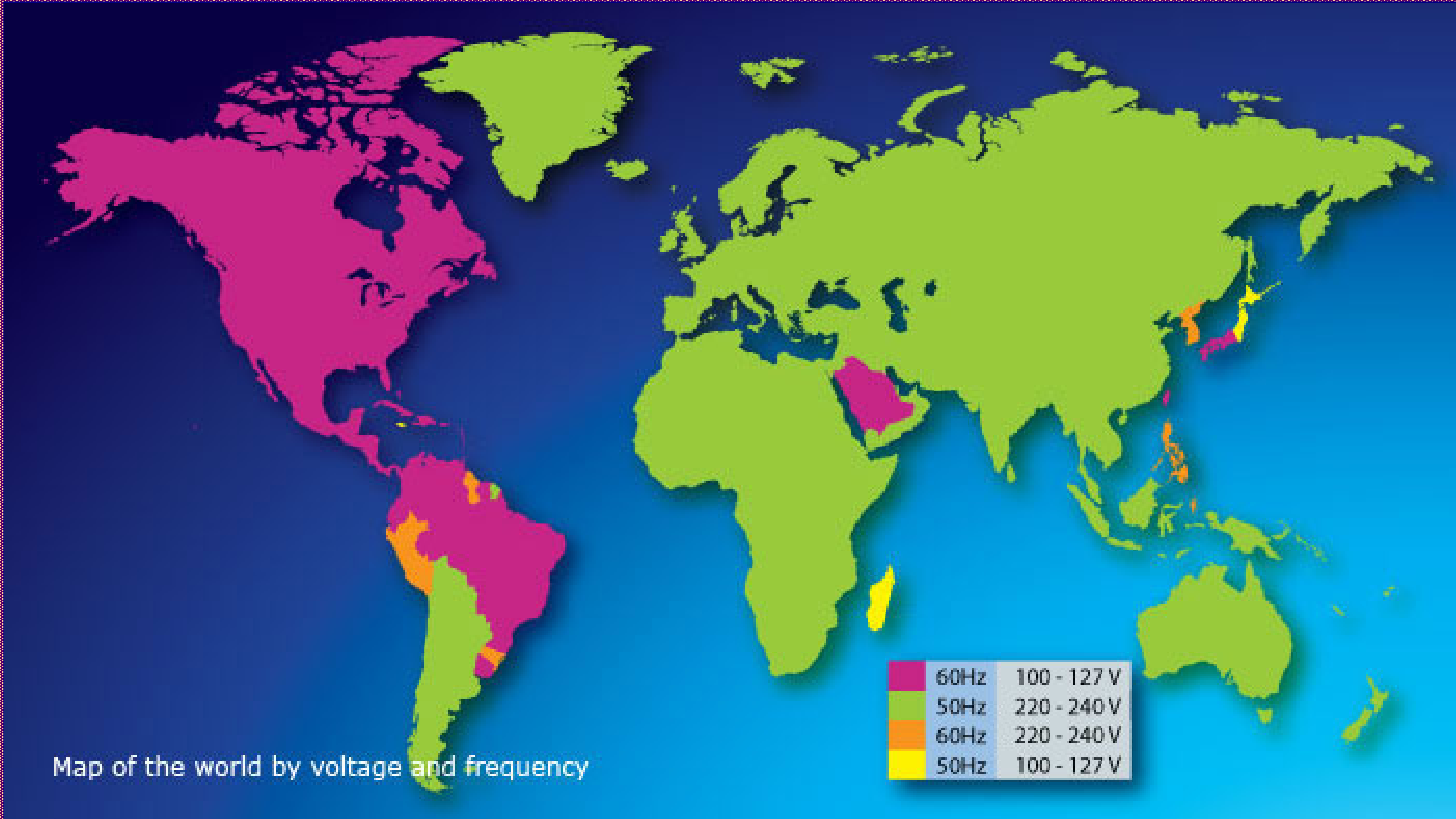
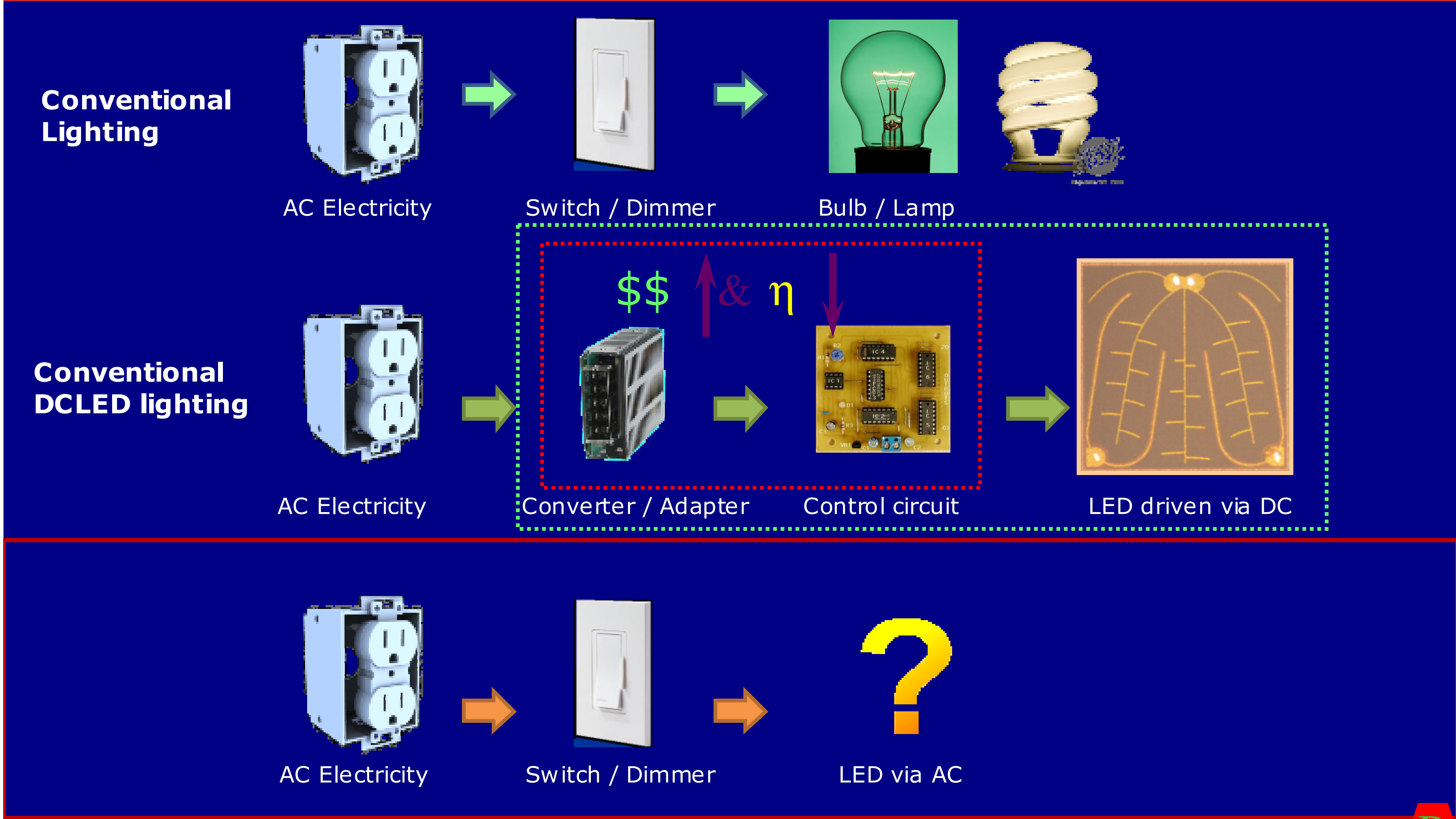
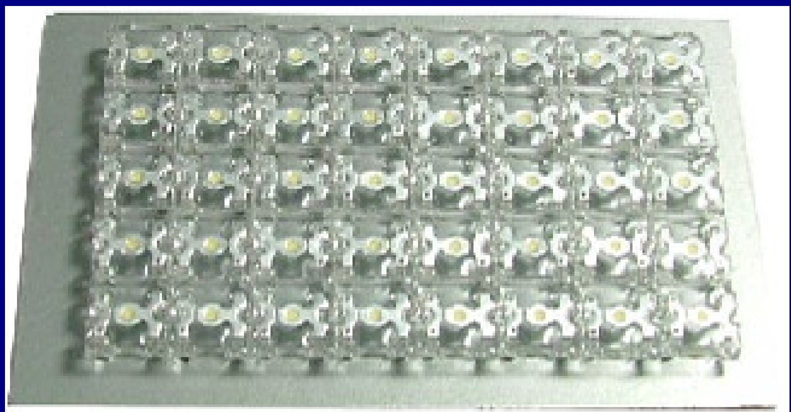


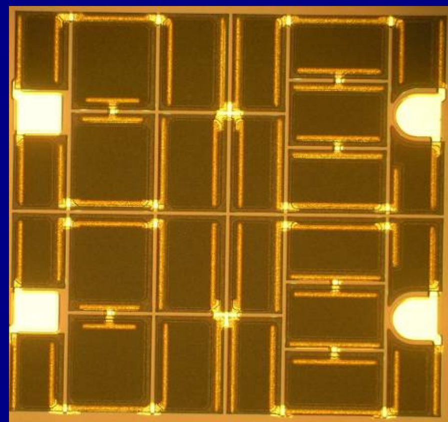
From Light Bulb to LED



AC LED Introduction

- ***What is AC LED?***
  - **AC LED is a single process-integrated LED with multi-cells that can be directly driven by AC utility without extra external device**
  - **The chip size and the number of cells can be customized to fit for all demands.**
- ***Different approaches***
  - **AC LED Module**
    - Conventional approach
    - Fabricated by packaging
  - **AC LED Single Chip (on-chip AC LED)**
    - Innovative concept
    - Integrated by wafer-level process
    - Complete system within a chip





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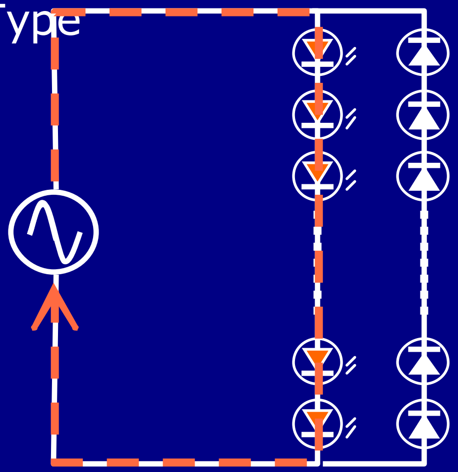
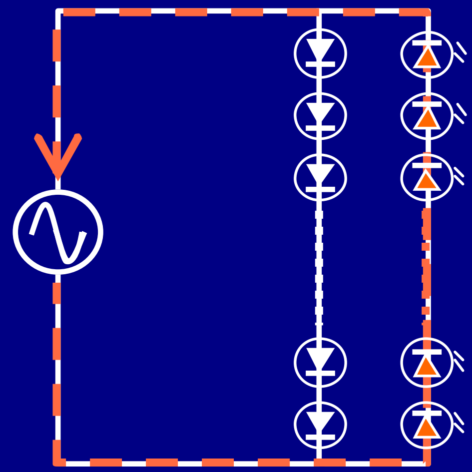
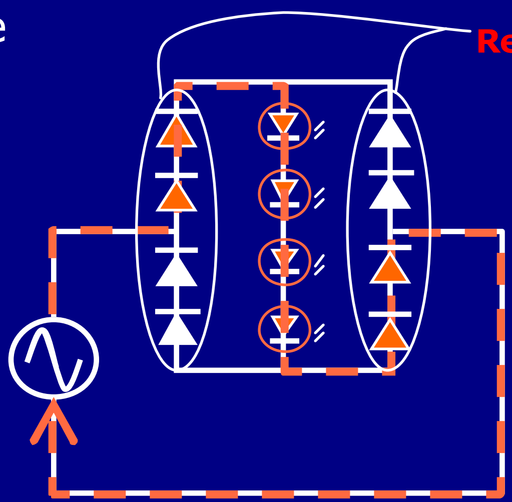
Circuit Layout for AC LED

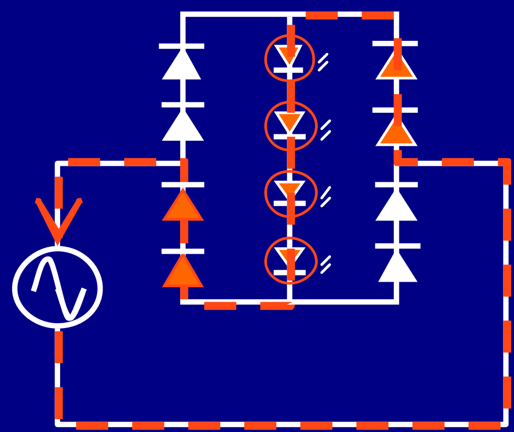
- **Circuit Layout**
  - Anti-parallel Type (Diode)





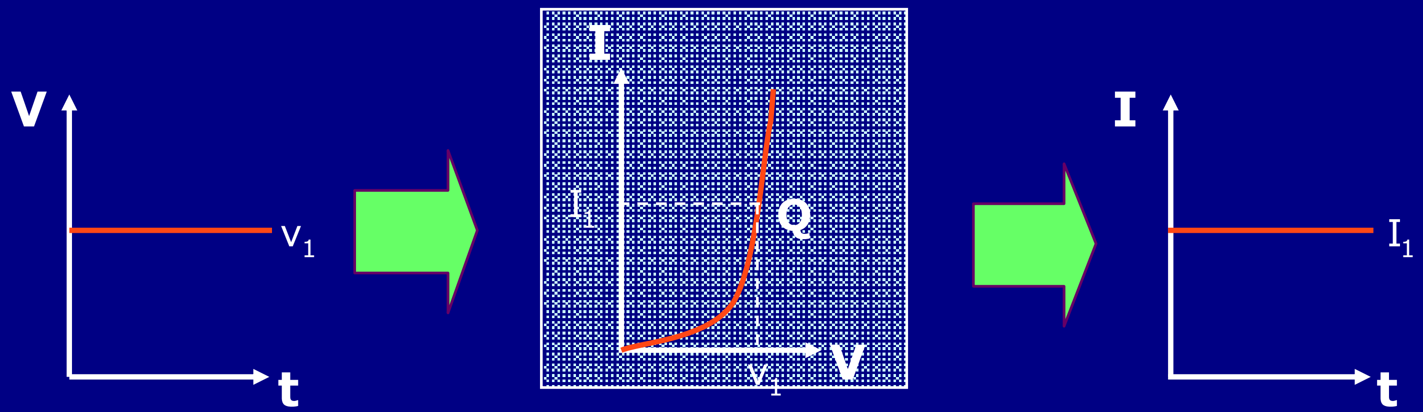
  - Bridge Type





Principle (I) : Dynamic Current Driven

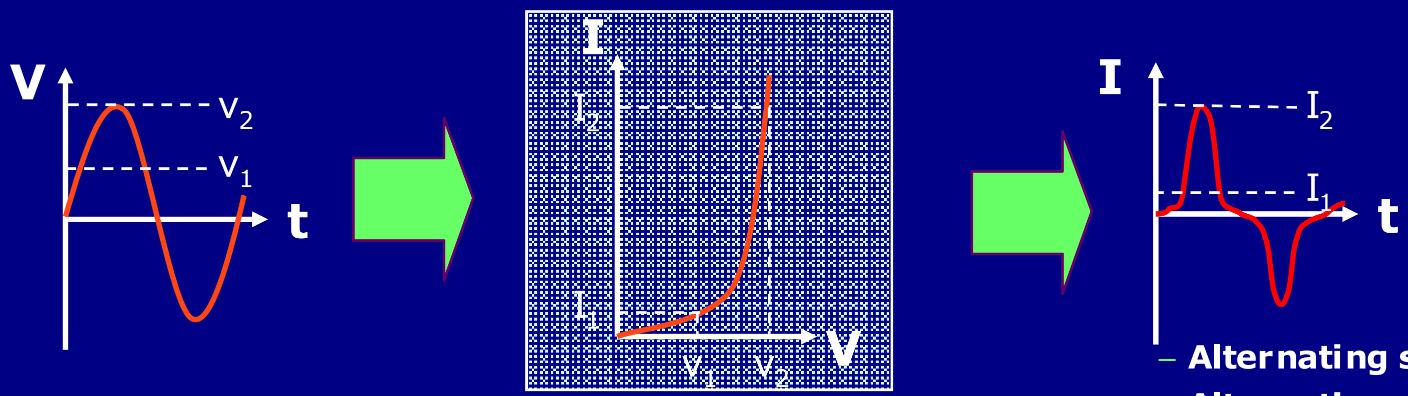
- **Operation Point for DCLED is static**



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**

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Principle (II) : Operation Current vs. Efficiency

- **Operation Current VS efficiency**
  - **If**
    $V_{s\text{-}Peak}$=40V
    $V_{f\text{-}ON}$ =20V
  - **Then**
    Duty cycle (turn off) ≈ 1/3 T
    (power consumption=0)**
    Duty cycle (turn on) ≈ 2/3 T
  - **Namely, 20~35V, 1/3 T**
    35~40V, 1/3 T

Diodes operate in High voltage regime in a considerably long time

⇓

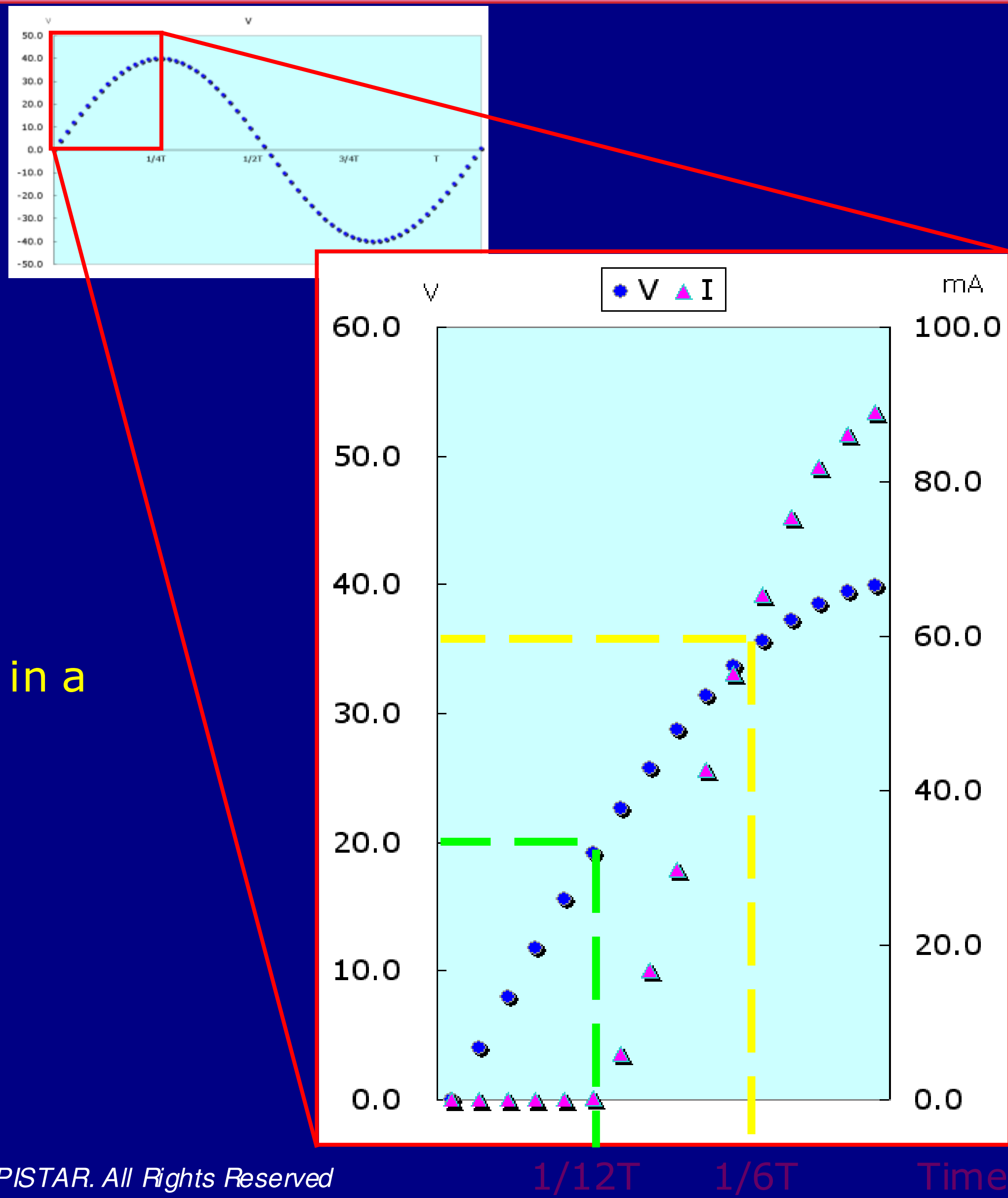
High Current

⇓

Higher Current Density

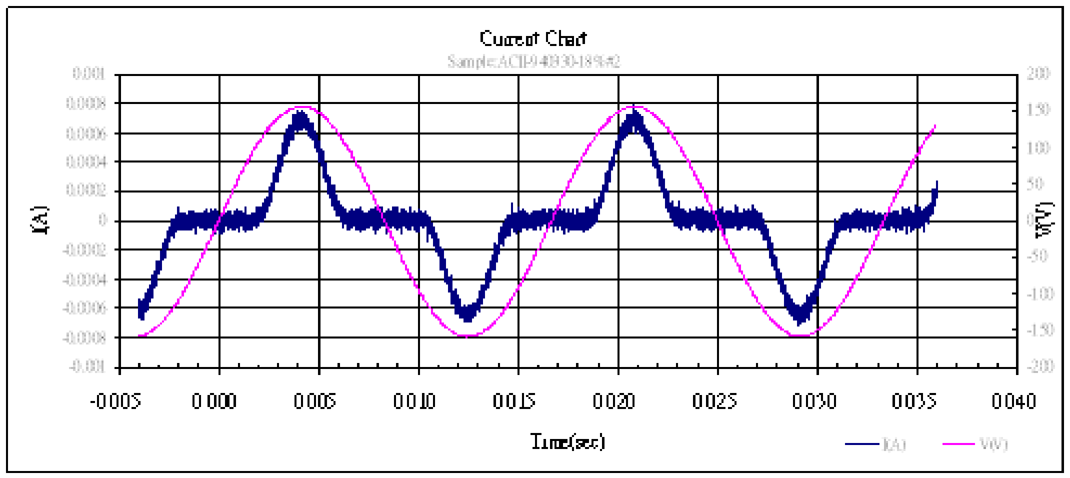
⇓

η ↓

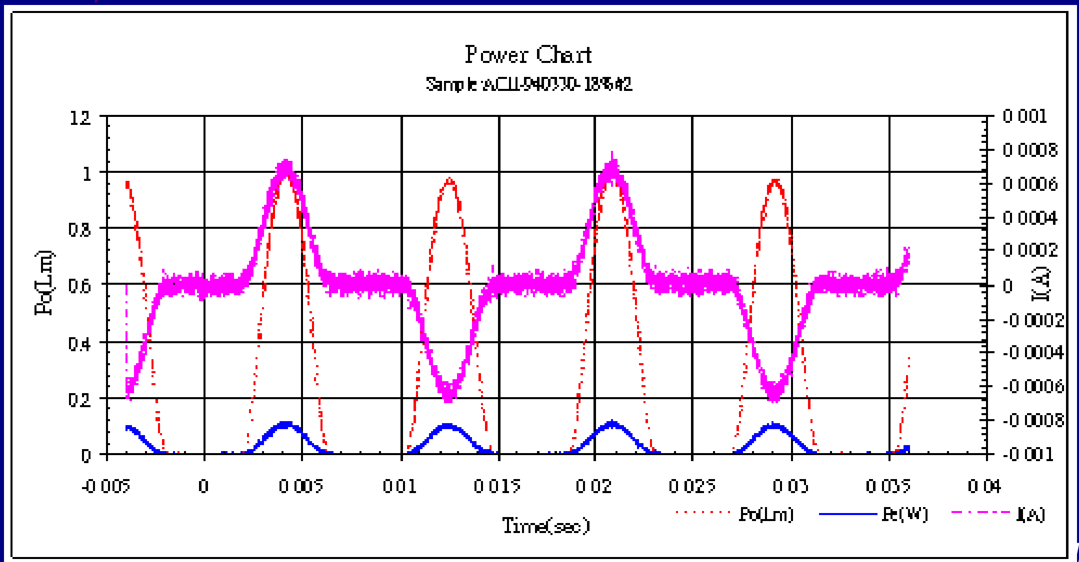


Principle (III): Power Factor

– *I-V Characteristics of AC LED*



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



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

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

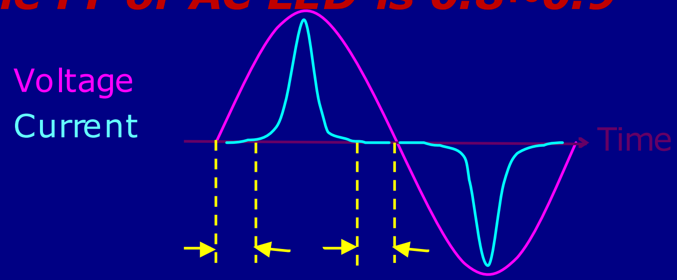
  - ***Apparent power:***

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

  - ***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. Decrease the cell number
2. Reduce the operation current
3. **Add resistor**

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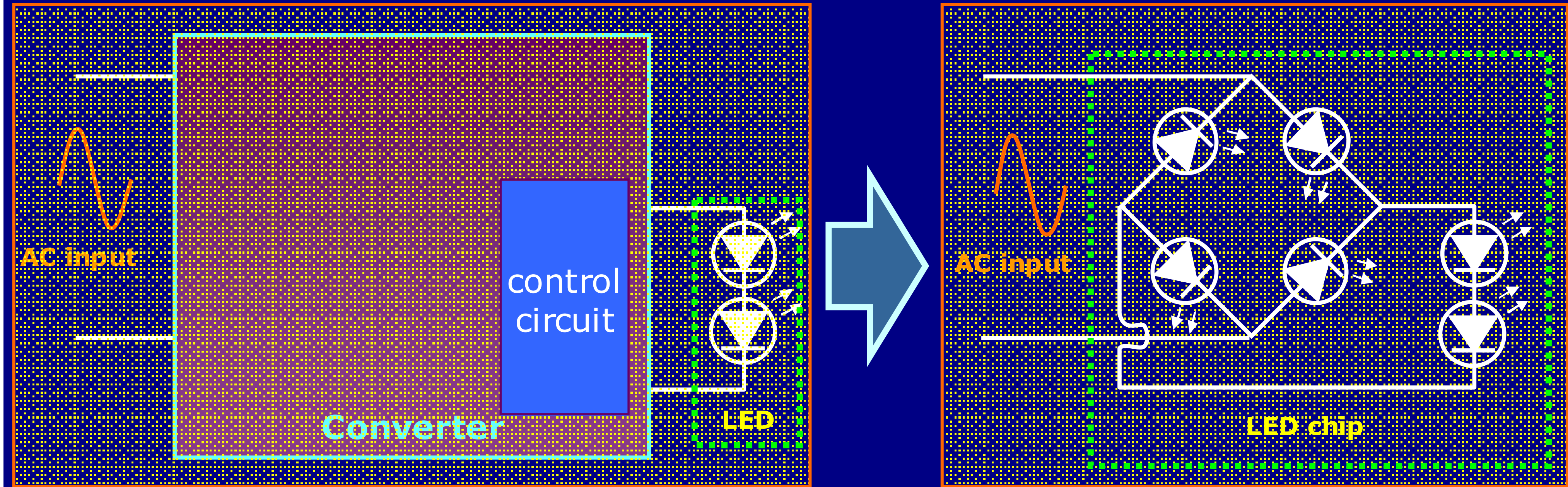
A Simple Design Concept

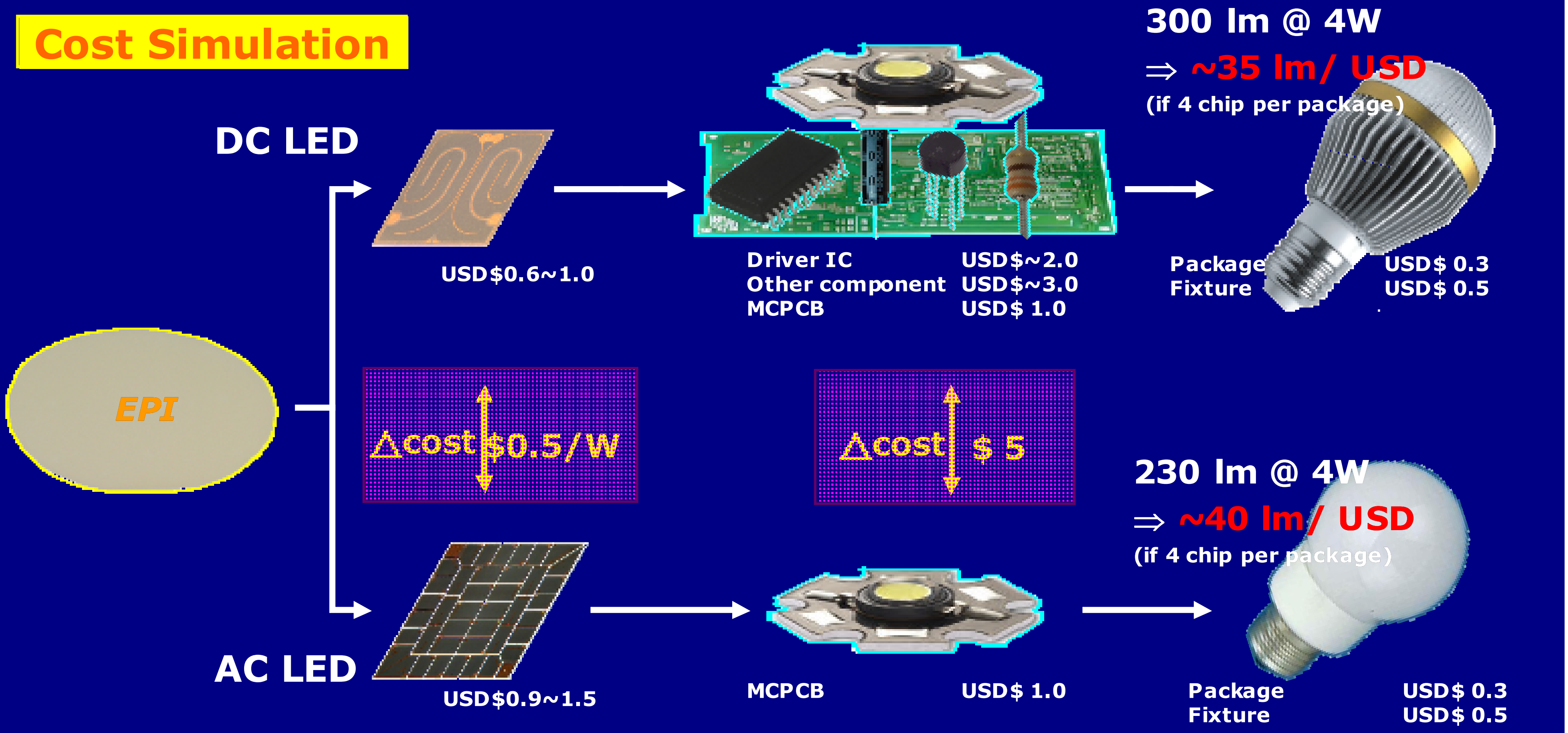
DC LED + converter *AC LED*



Design	DC LED + converter	AC LED
User-friendly	worse	better
Reliability	worse (converter)	better

Lower Cost (lm/$) Approach (4W)

Cost Simulation



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

AC LED Target Market

- Advantages
  - Lower the total cost
  - Less space needed
  - Without reliability concern about converter
  - Easy to be dimmable

- Niche Market
  - Spot lighting: 3W/200lm; 5W/300lm; 7W/400lm
  - Lamp holder: GU10; E12, E14, E27
  - 100V/110V; 220V/230V

Episatr--AC55

Product Type: ES-CABLAC55

1W solution @110V

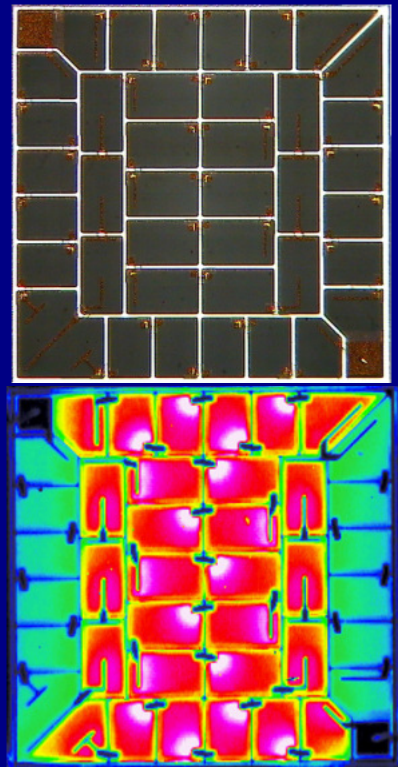
Vf @ 10mA: 110.0 ~ 112.5 V

Wld: 455.0 ~ 460.0 nm

PS : 1.No Resistor
2.η is estimated

(Customer Packaging Data)

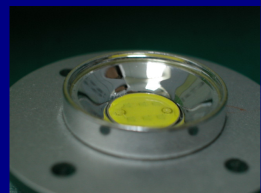
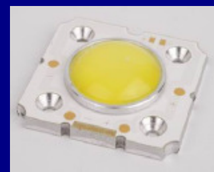
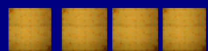
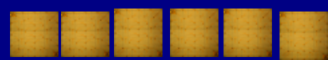
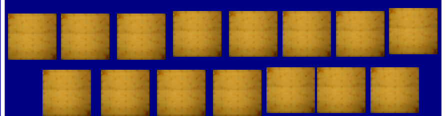
Name	X	Y	Lumen	CCT	I	V	Efficiency
No./Unit			lm	K	Irms	Vrms	lm/W
Min	0.357	0.414	56.29	4575	10.0	92.0	68.0
Max	0.369	0.430	62.67	4828	10.0	94.0	74.1
Avg.	0.363	0.422	59.37	4692	10.0	93.3	70.7
StdDev	0.006	0.008	3.48	112	0.0	0.9	



AC LED Applications

Applications	Chandelier	Table Lamps	Recessed Downlight
			
Bulb Type			
Replace	40W Candle Light ↓ 4W AC LED	60W Incandescent ↓ 6W AC LED	50W PAR38 ↓ 15W AC LED
AC LED			

Use AC55 to Form Lamps

Type	4W AC LED	6W AC LED	15W AC LED
			
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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Epistar--AC99

Product Name: **ES-CABLAC99**

Under development

4W solution @110V

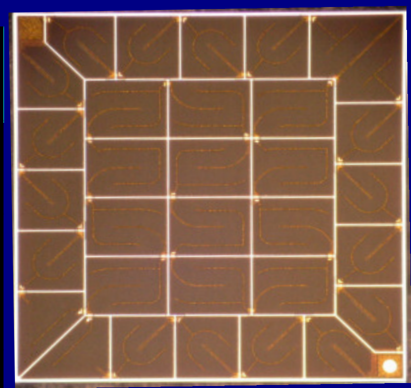
Vf @ 50mA: 92.5 ~ 95.0 V

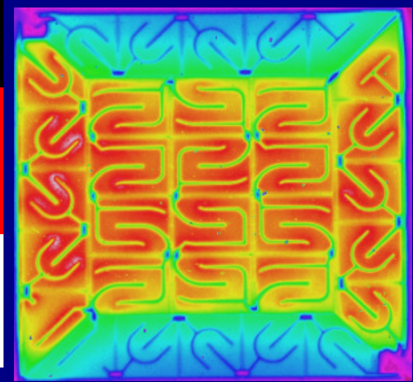
Wld: 452.5 ~ 460.0 nm

PS : 1.No Resistor
2.η is estimated

(Customer Packaging Data)

Name	X	Y	Lumen	CCT	I	V	Efficiency
No./Unit			lm	K	Irms	Vrms	lm/W
Min	**0.351**	**0.404**	**221.3**	**4858**	**50.0**	**75.4**	**65.2**
Max	**0.356**	**0.414**	**227.2**	**4970**	**50.0**	**76.2**	**66.2**
Avg.	**0.354**	**0.410**	**224.6**	**4903**	**50.0**	**75.7**	**65.9**
StdDev	**0.002**	**0.005**	**2.96**	**49**	**0.0**	**0.4**	



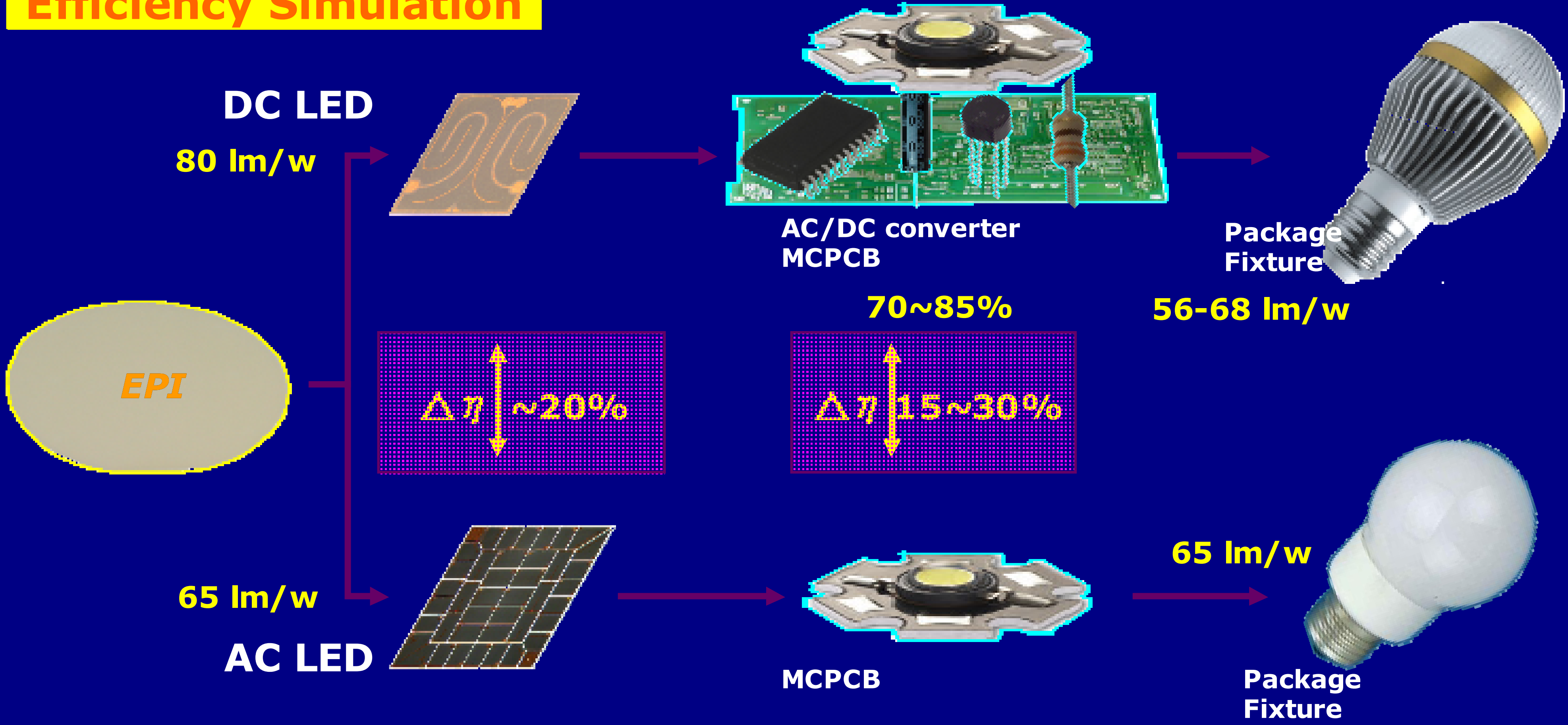


Technology Challenges of AC LED

- ☑ Luminous Efficiency & Droop Effect
- ☑ Heat Dissipation
- ☑ Electric Power System Variation
- ☑ Pulse and Reverse-bias Driven

Total Efficiency Comparison

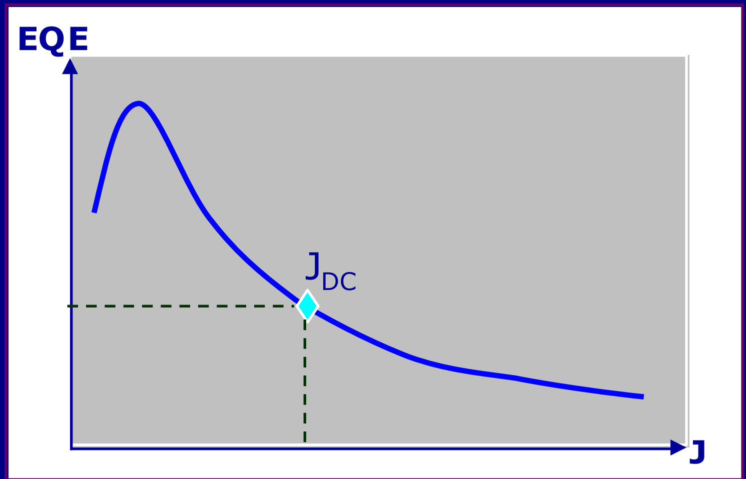
Efficiency Simulation



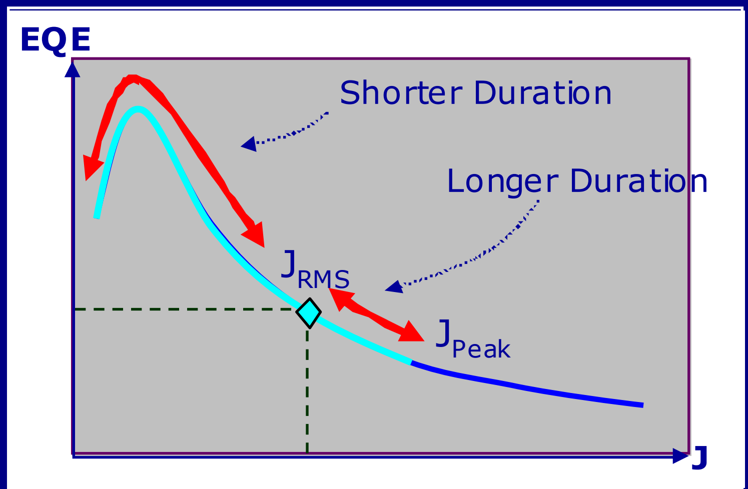
Note: The cost of LED chip are only for reference because it depended on performance and chip size.

Efficiency Droop Effect

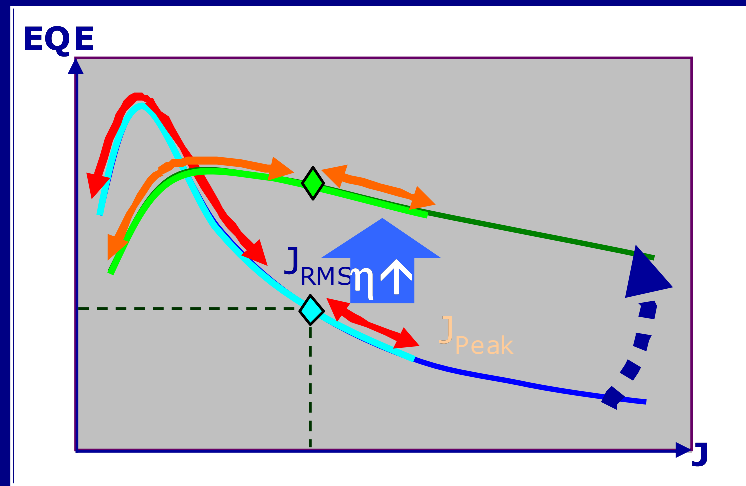
– **DC LED**



– **AC LED**



Constant current ⇒ Constant η



Varied current ⇒ Varied η

Normally, $\eta @ J_{RMS} < \eta @ J_{DC}$

due to the longer duration between Jpeak and Jrms

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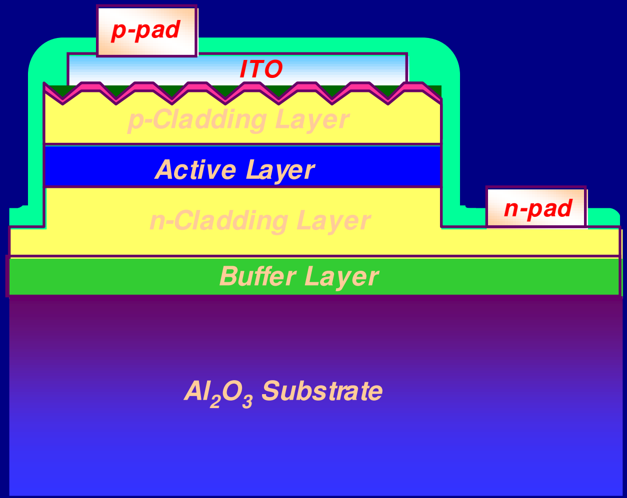
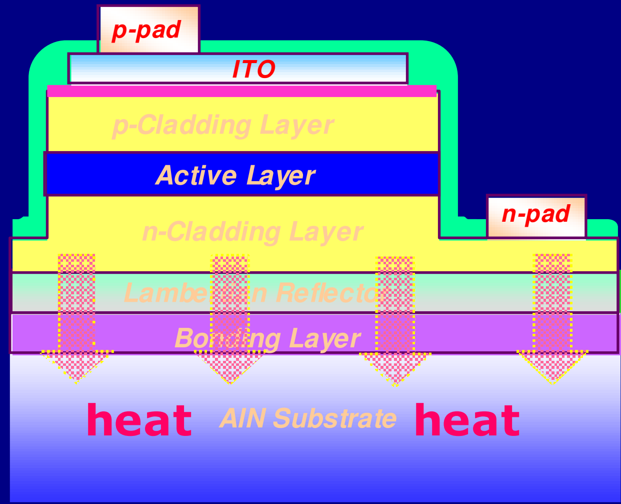
Heat Dissipation

Venus-Series



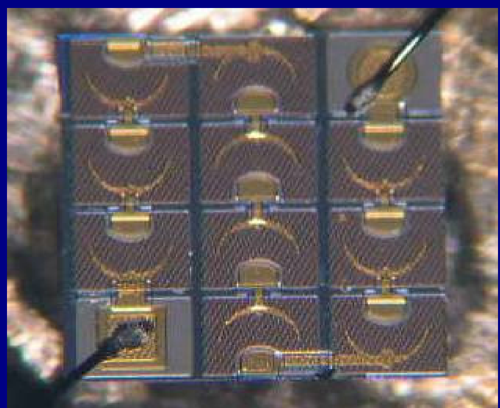
Sapphire k=35 w/m-k

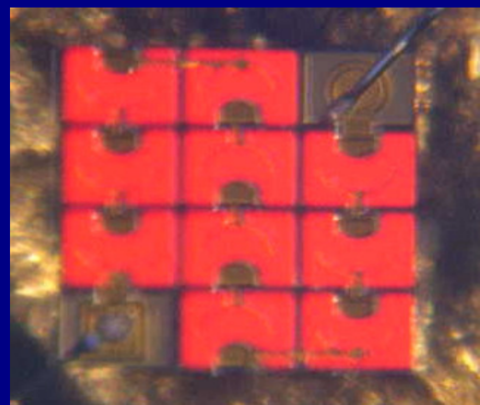
Saturn-H Series



AlN k=150 w/m-k

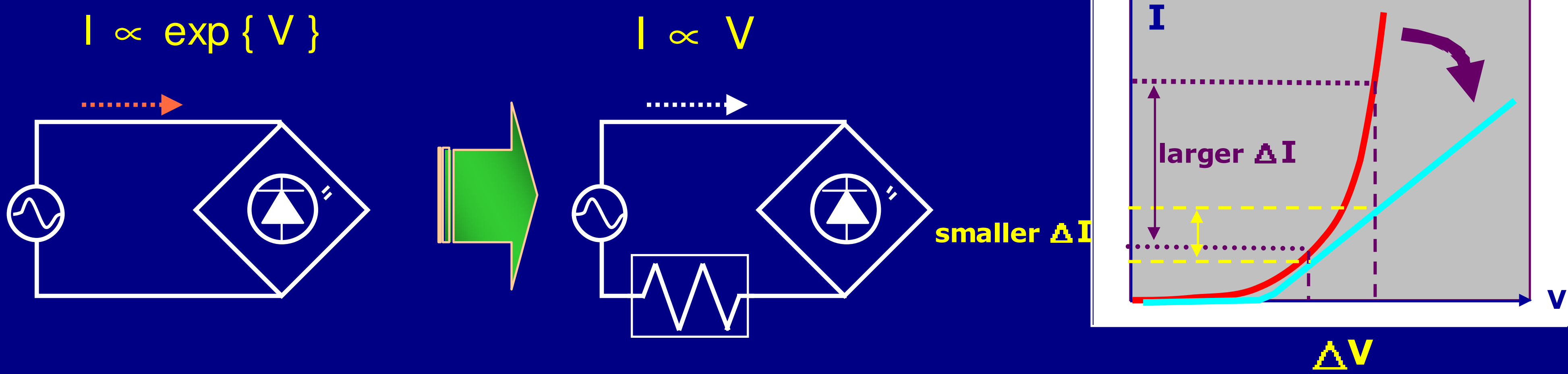
- **Apply bonding technology to AC LED for good heat dissipation!**



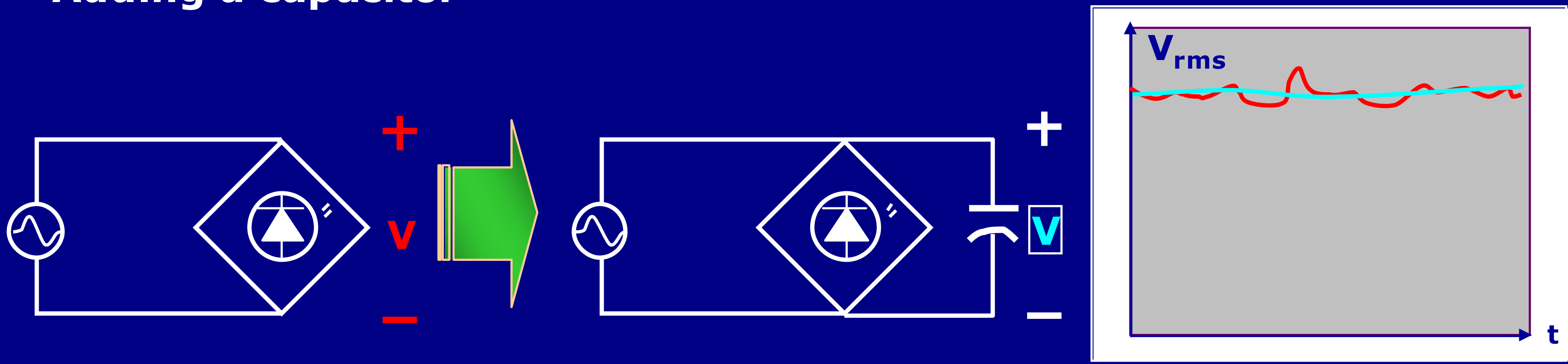


Solution for Power System Variation

- **Adding a resistor**



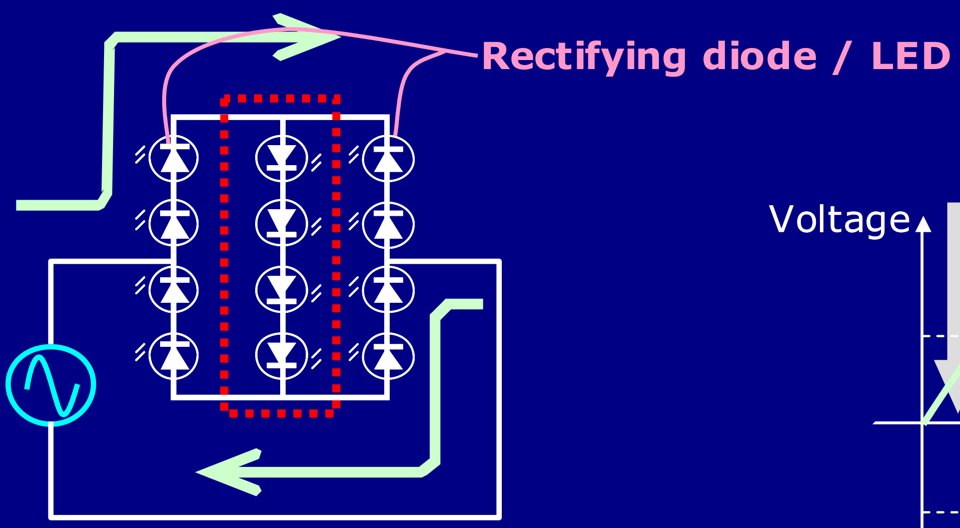
- **Adding a capacitor**



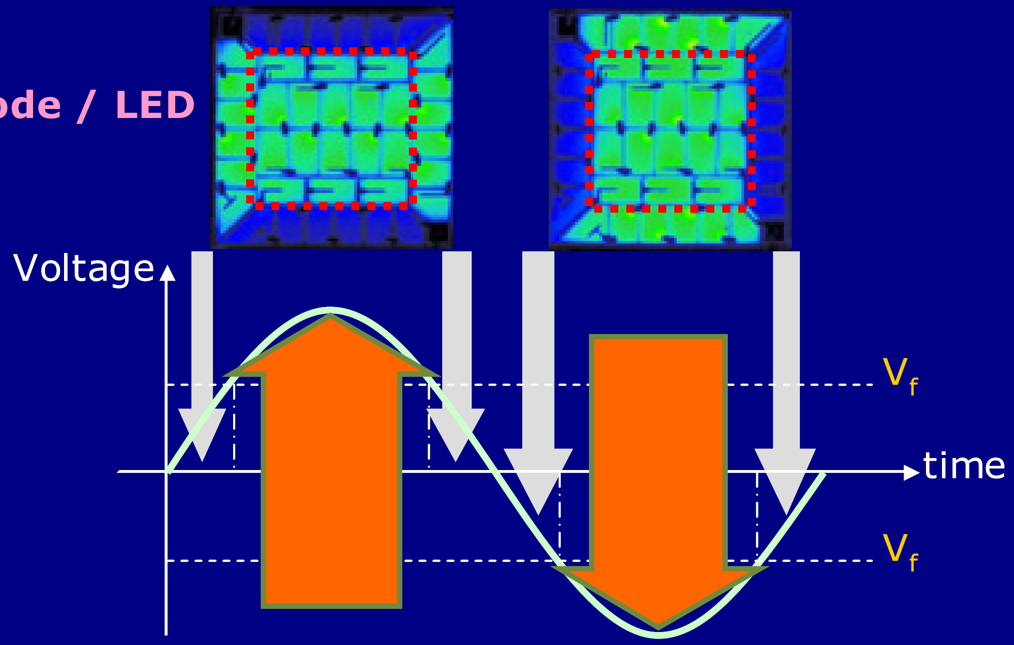
Pulse and Reverse-bias Driven

Compared to DC LED, it's a brand-new operation mode. Therefore, it needs

- Advanced epitaxial structure : breakdown voltage
- Modified chip process : reverse leakage
- Optimized device layout : efficiency



Bridge type



Outline

- Market Trends for HB-LED and Lighting
- Technical Trends & Challenges for LED Lighting
- AC LED for Lighting
- Summary

Summary

- Higher energy efficiency and longer life time enable LED to play an important role in driving the transition of lighting industry for next few years.
- AC LED, a simple and user-friendly solution, is suitable for spot light with relatively lower power fixture like candle light, Incandescent and PAR38.
- White light AC LED chip with luminous efficiency of 70 lm/W is achieved.
- Several technology challenges of AC LED have been addressed and need to be further improved for broadening application scope.


Thanks for Your Attention