



Tsinghua University, Physics Colloquim, Hsinchu, Taiwan, May 20, 2004

# **The Next Generation Lighting Technology**

## **- Semiconductor Lighting**

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**Opto-Electronics & Systems Laboratories (OES )**

**Industrial Technology Research Institute (ITRI )**

**Taiwan, ROC**

# Semiconductor Lighting

- 發明
- 物理 / 科技
- 應用 / 生活
- 產業

# Semiconductor Lighting

## 發明

- 創意
- 創新
- 創造

# *Major Milestones in Photonics*

- *Invention of Light Bulbs (1882)*
  - *Beginning of man-made electrically-generated light*
- *Invention of Coherent Light (1960's)*
  - *Beginning of quantum optics (coherent, collimated ...)*
  - *Invention of transistors(1948)*
- *Nano-photonics (2000s)*
  - *Beginning of a new un-chartered territory*  
*e.g. Photonic crystals, QD devices, holey fibers*

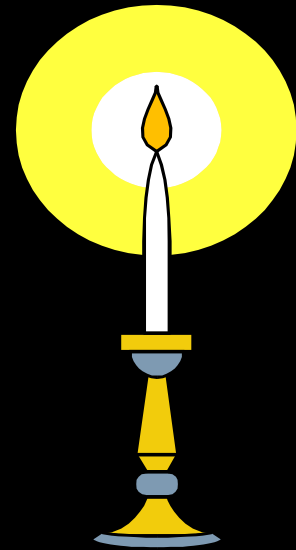
# 光電技術的起源-1880s

光電科技的發展過程中、充滿了突破性技術的發明，因而給人類生活帶來革命性的改變！  
1882年愛迪生發明白熾燈、這是人類第一次用電產生的光源！  
這個發明不但是有史以來、人類第一次真正解脫了黑暗的約束、更開創了近代光電科技發展的首頁！

Let There Be Light

- *Genesis*

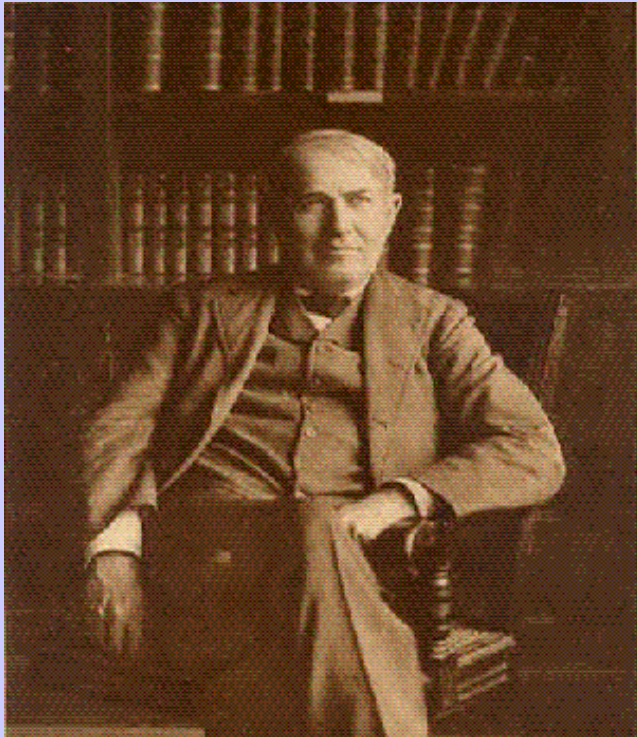
# Light :



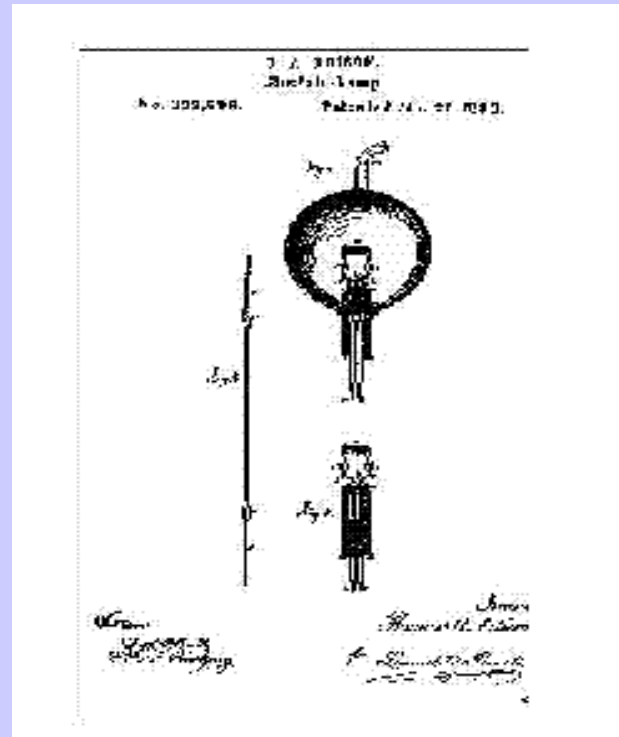
# Edison's Lamp - 1882

" We are striking it big in the electric light, better than my vivid imagination first conceived. *Where this thing is going to stop Lord only knows.*"

- Thomas Edison October 1879



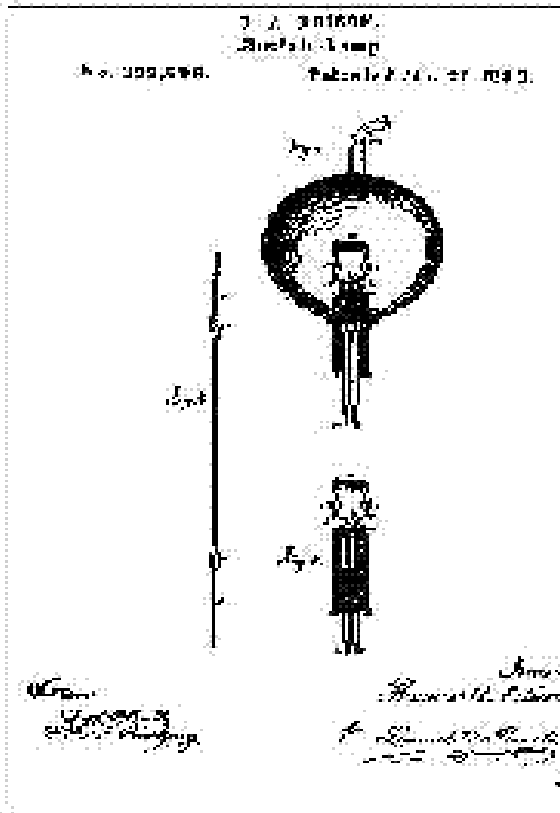
Thomas Edison, 1882



September 4, 1882



# Edison's Incandescent Lamp - 1882



September 4, 1882

*“The first step is an intuition- and comes with a burst, then difficulties arise. – This thing gives out and then that- ‘Bugs’ –as such little faults and difficulties are called- show themselves and months of anxious watching. Study and labor are required before commercial success or failure- is certainly reached.... I have the right principle and am on the right tracks, but time, hard ward, and some good luck are necessary too.”*

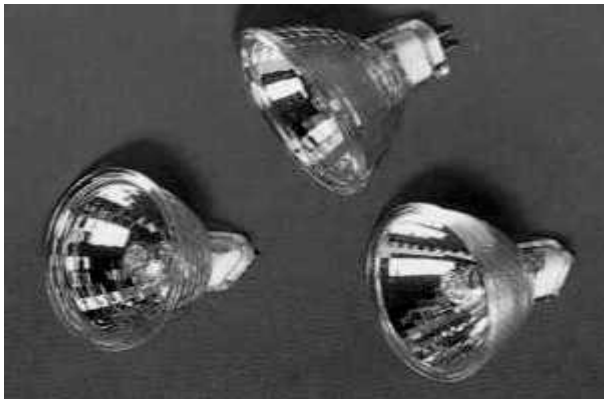
*- Thomas Edison, describing his inventive process, 1878*

# Traditional Lighting Sources

**Incandescence bulbs**



**Compact fluorescence bulbs**

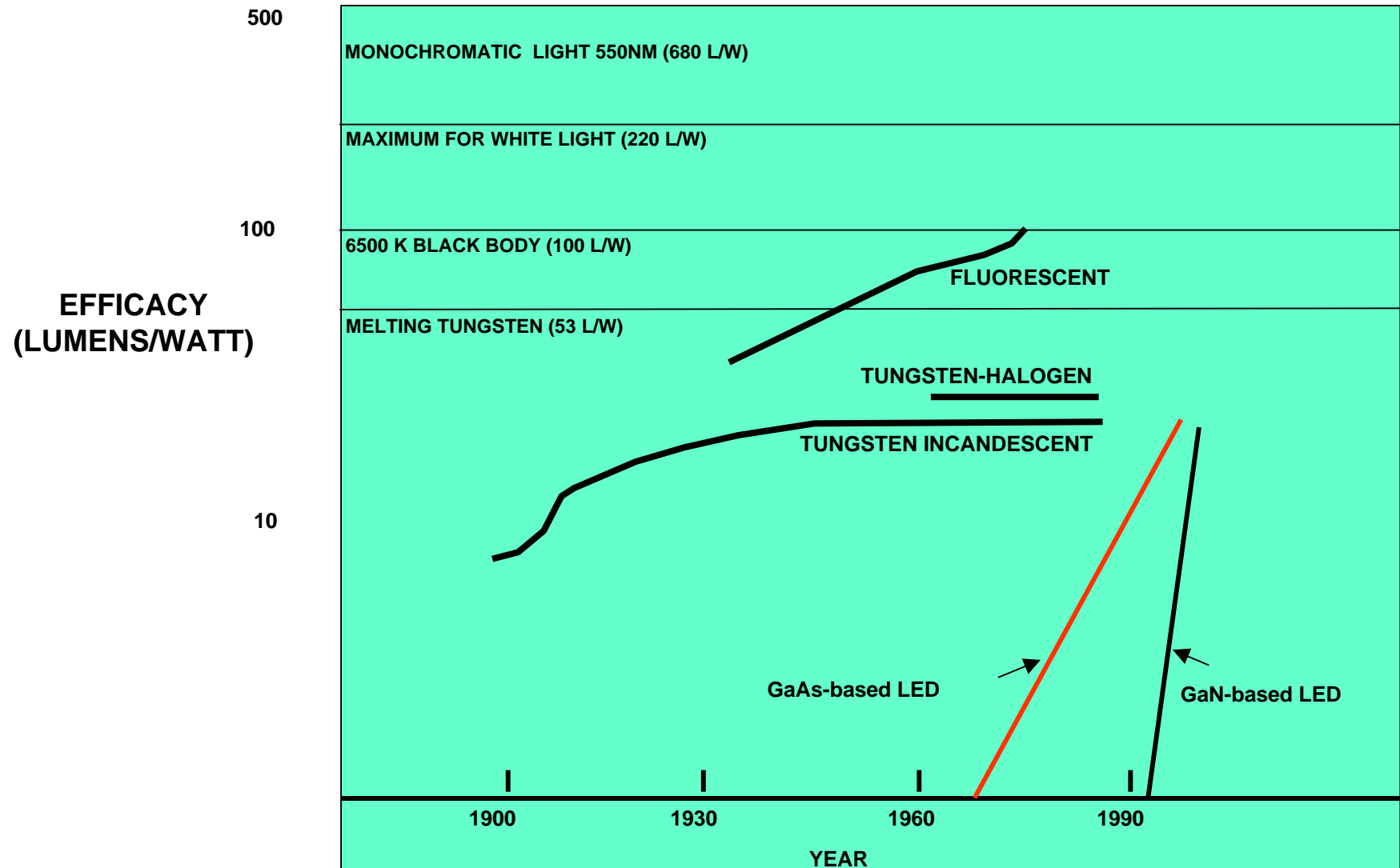


**Halogen bulbs**

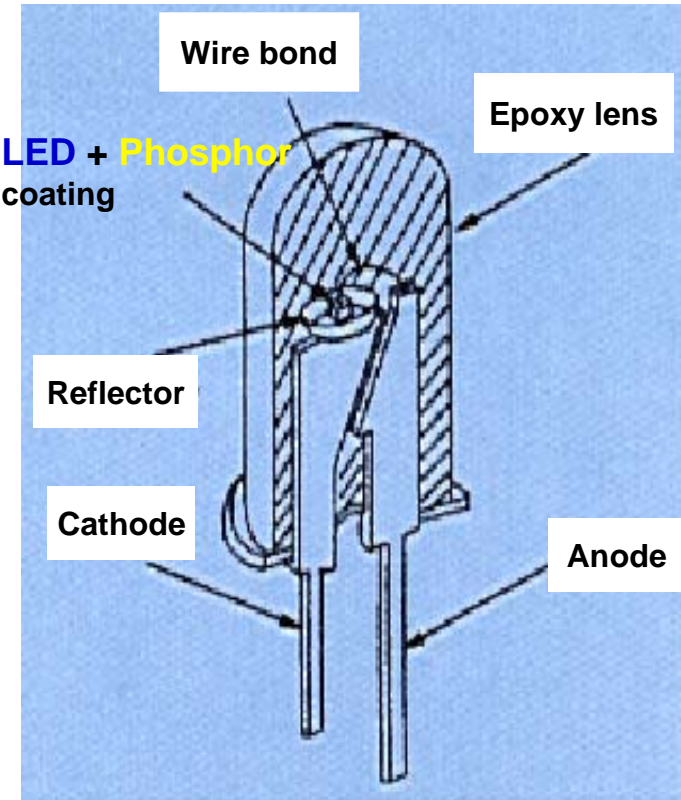
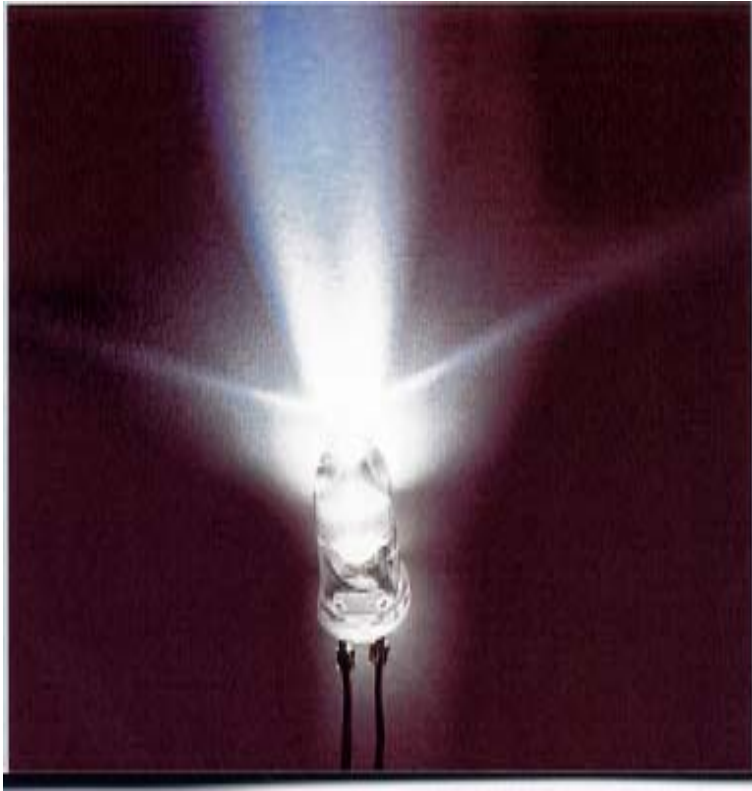


**Fluorescence bulbs**

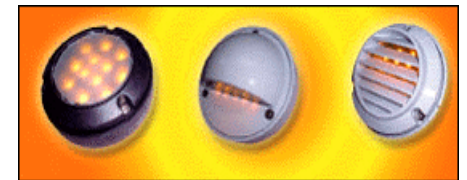
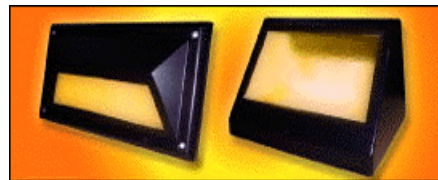
# Evolution of Lighting Technologies



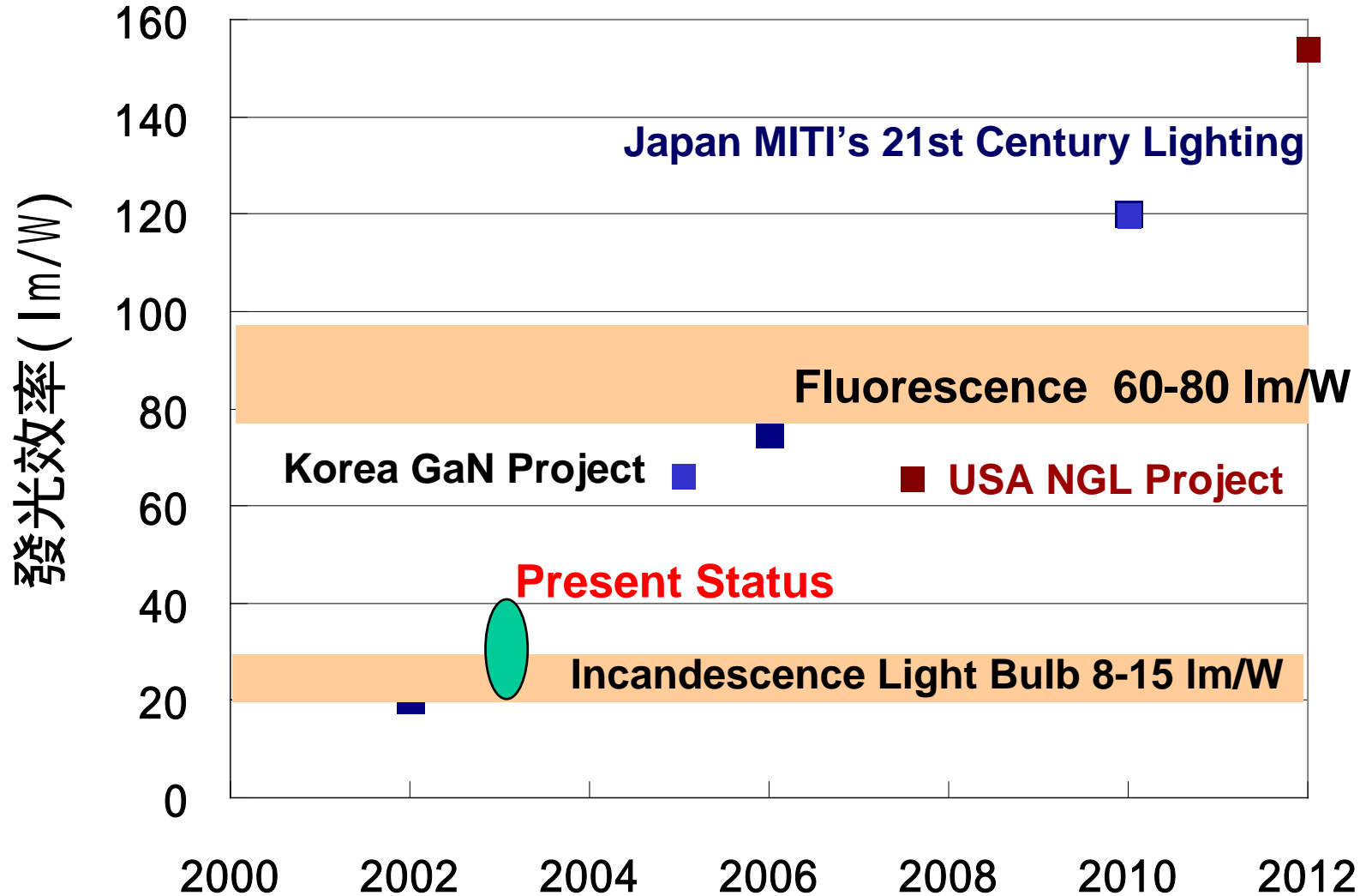
# White LED - 1996



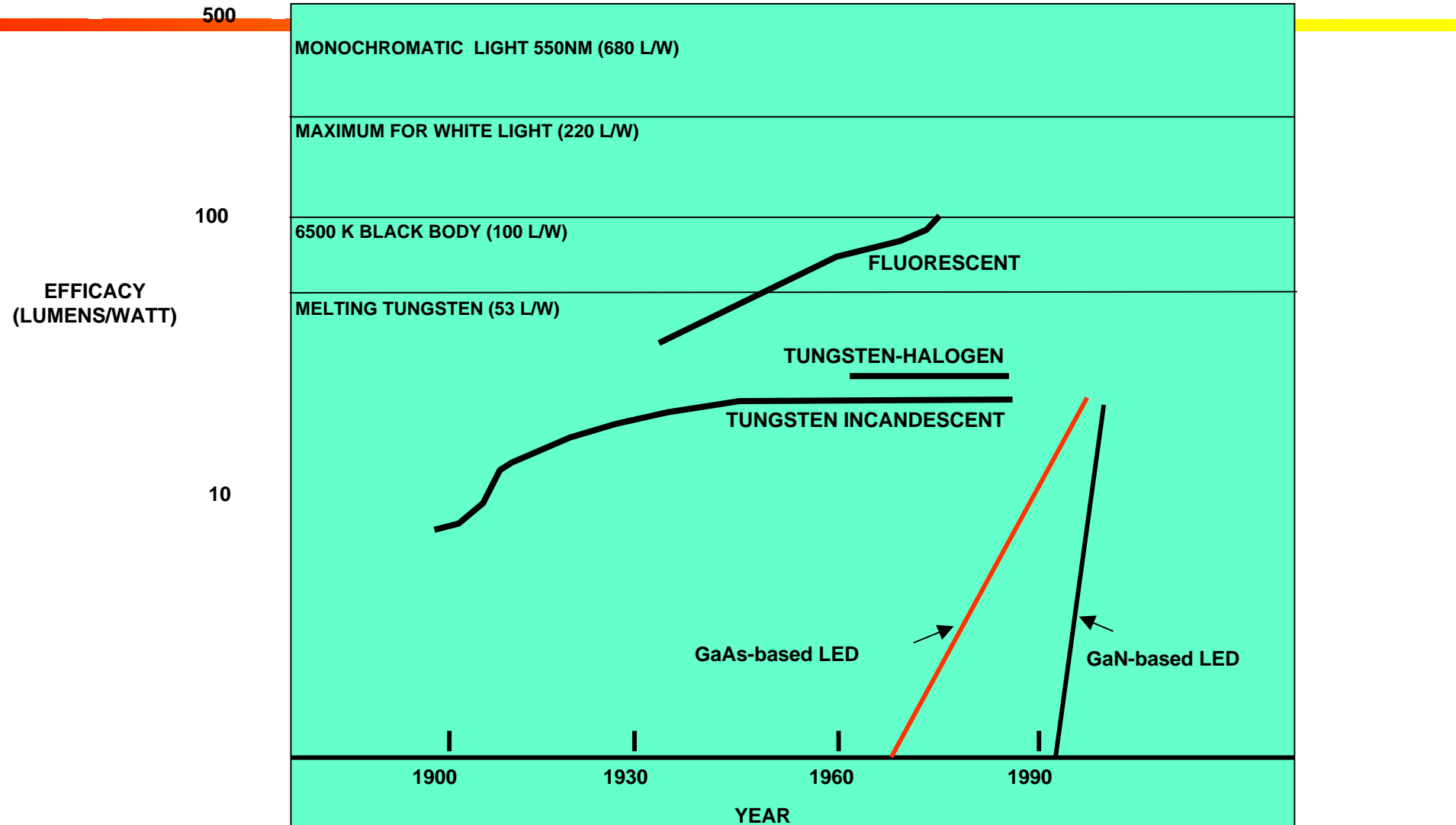
# LED Light Bulbs - 2000



# White LED Efficiencies

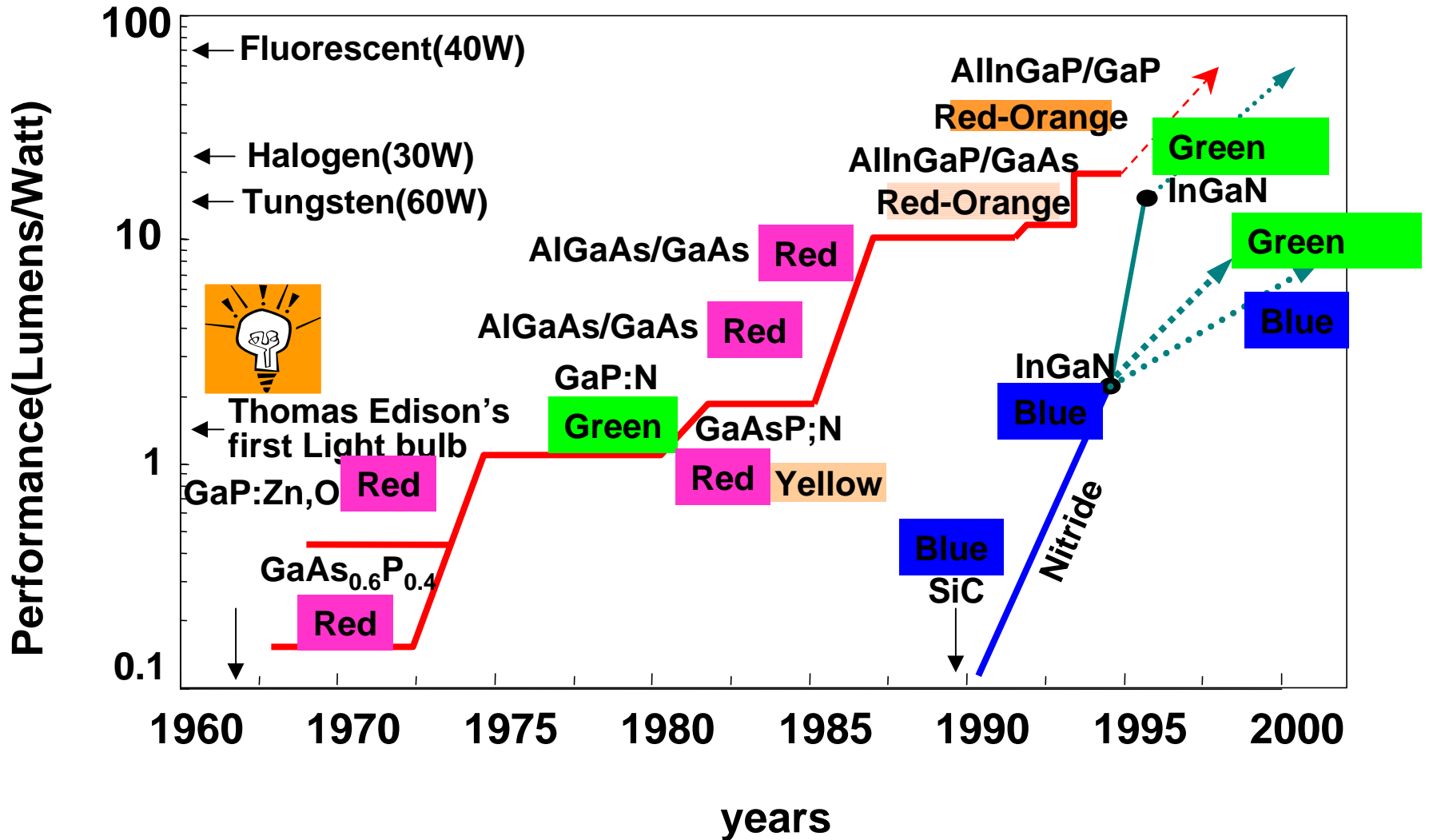


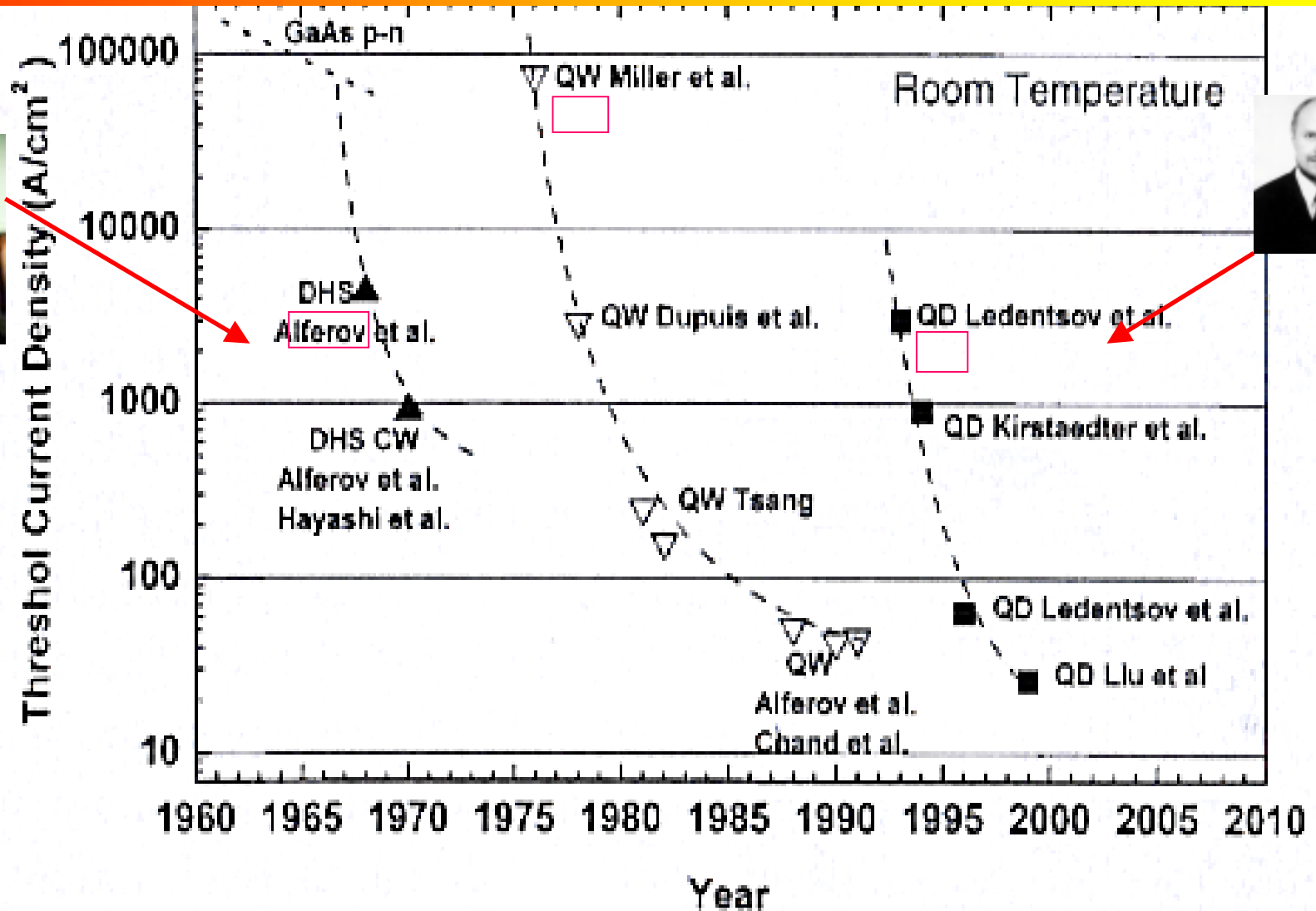
# Evolution of Lighting Technologies



1909年愛迪生創設的實驗室來了一位年輕的化學家 Irving Langmuir、他繼續做燈炮相關問題的基礎研究、他發現如果把氮及氬氣加到燈炮裏可以大大增長燈炮的壽命！他還發明了單分子層(mono-layer)的觀念及製作單分子層的工具、Langmuir的研究建立了表面物理科學的基礎、因而得到1932年的諾貝爾獎！他的研究也可以說是奈米科技研究的開始！從這些發展、我們可以看出光電科技和奈米科技密切的關聯性！



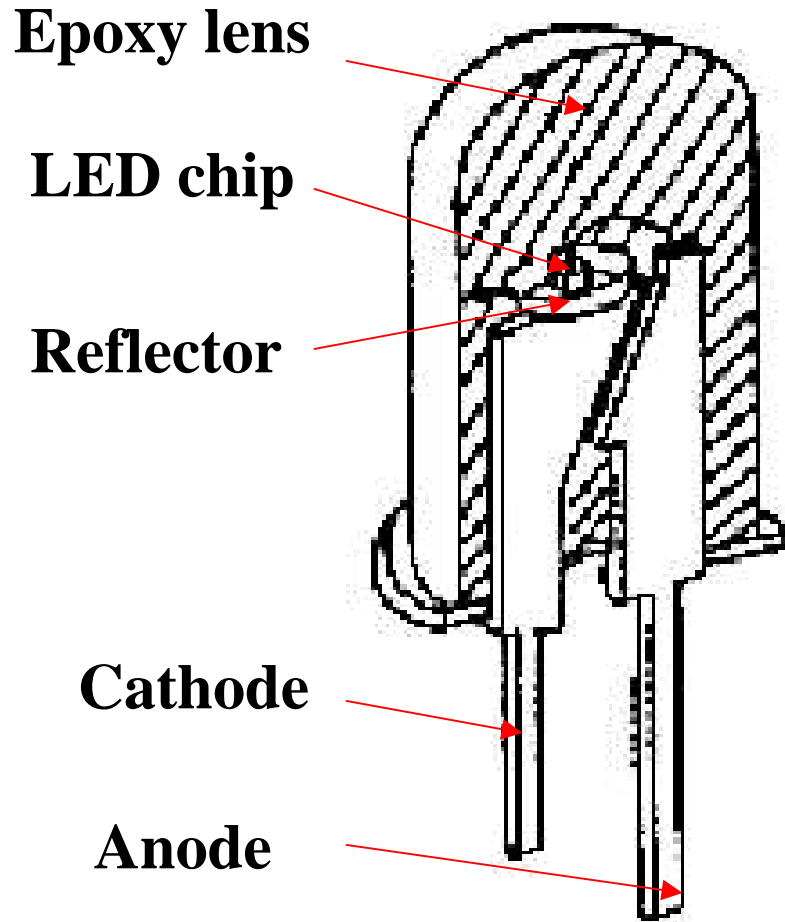




# Solid State Lighting Technology

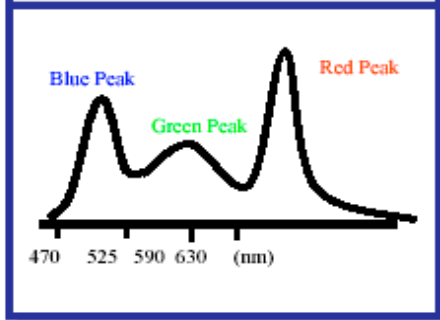
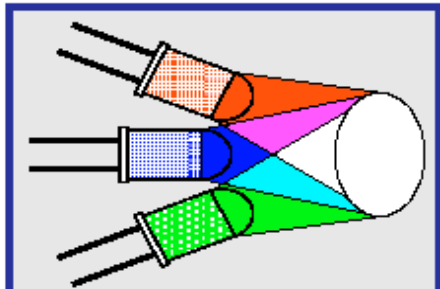
- 發明
- 物理/科技
- 應用/生活
- 產業

# LED (發光二極體)



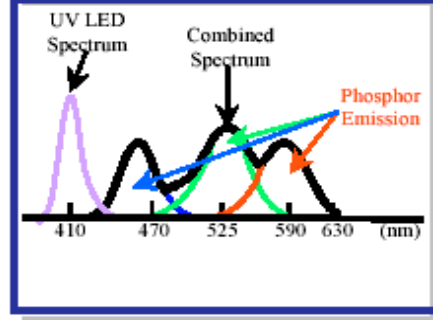
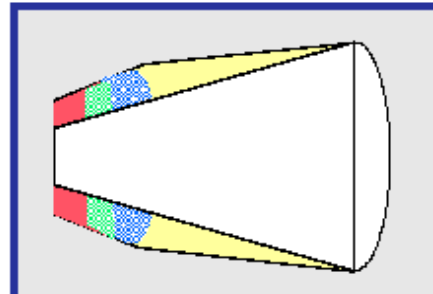
# Main Technology for White LED

Red + Green + Blue LEDs



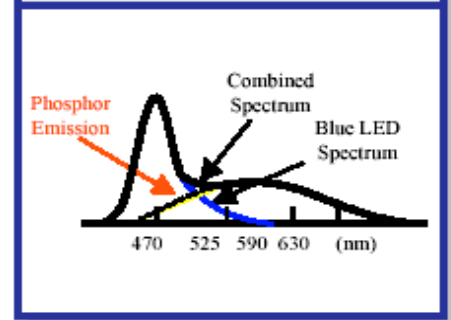
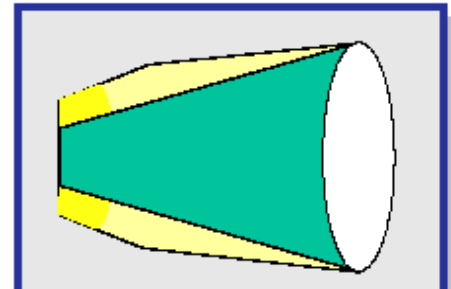
RGB LEDs

UV LED + RGB Phosphor



UV LED + RGB phosphor

Binary Complimentary



Blue LED + Yellow phosphor

Efficiency

Excellent

Wavelength depended

Good

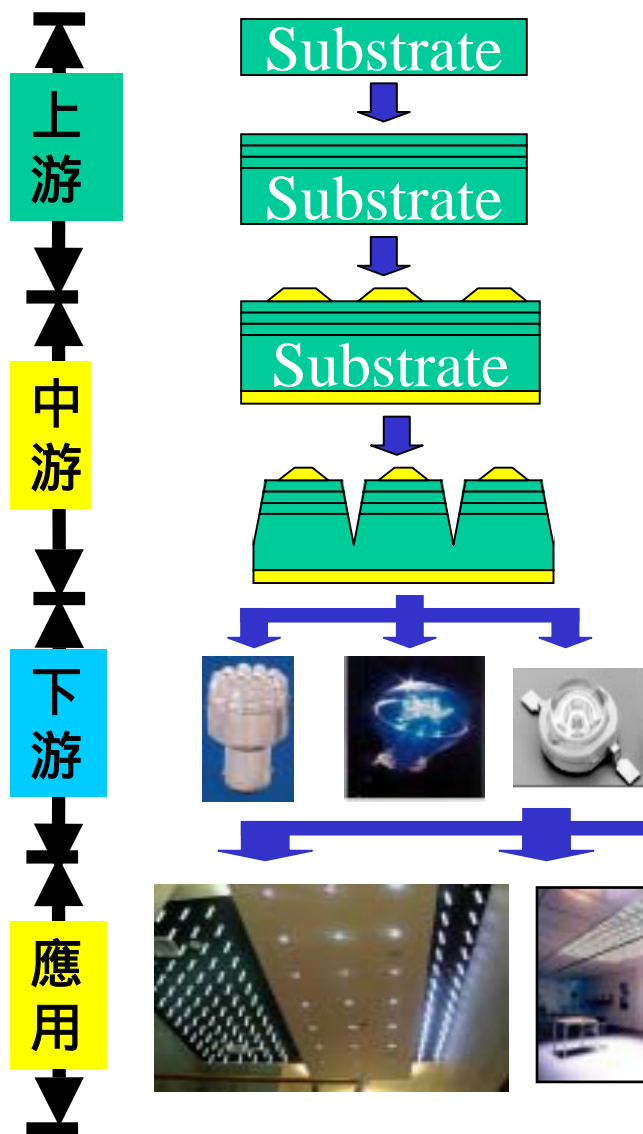
CRI

Excellent

Excellent

Fair

# 白光LED製作流程



## •單晶基板製作:

HVPE生長、Laser lift-off (前瞻計劃)

## •磊晶生長:

MOVPE (業界科專)

## •元件製作:

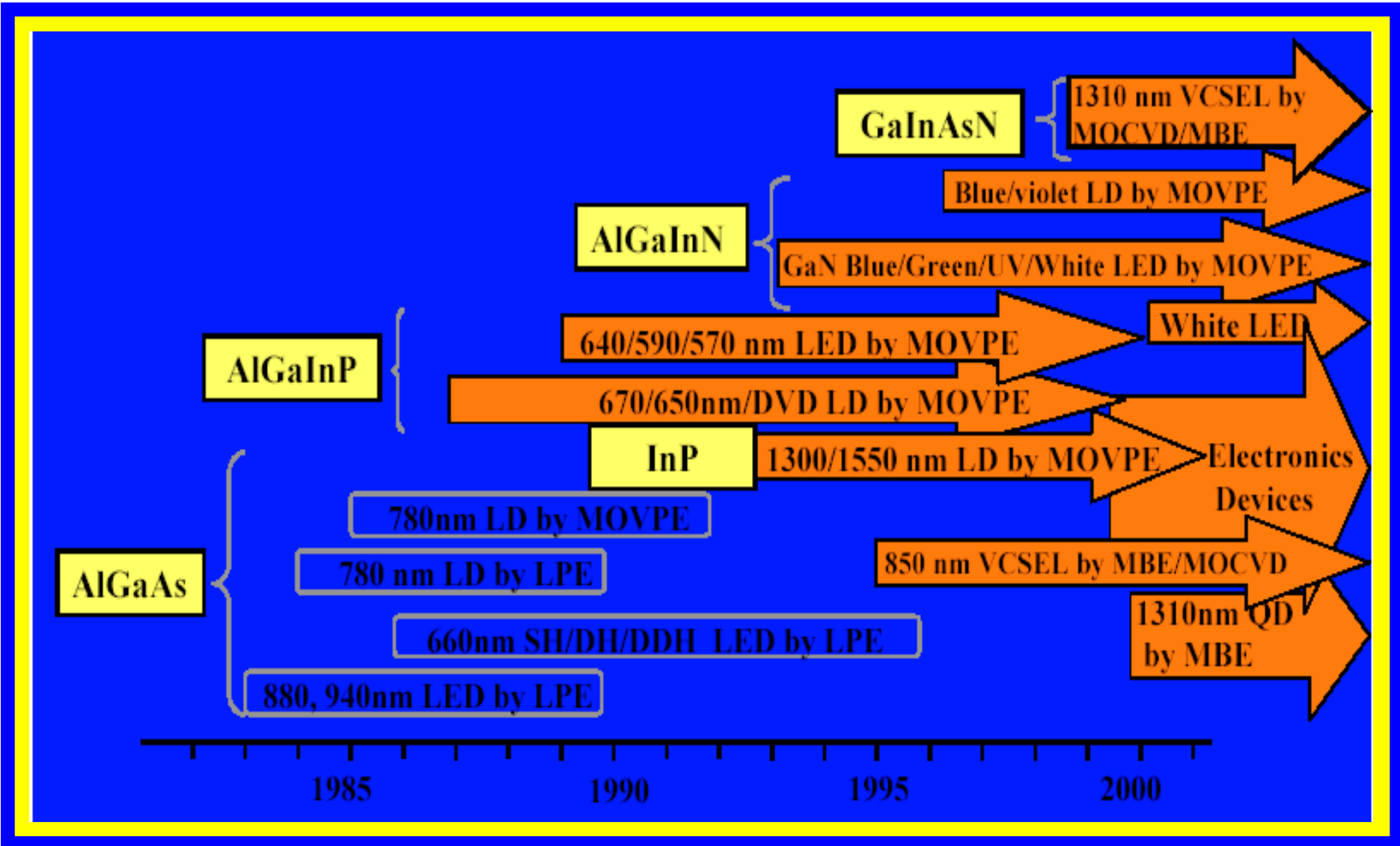
透明導電膜、金屬電極、光罩、蝕刻、磨薄(業界科專)

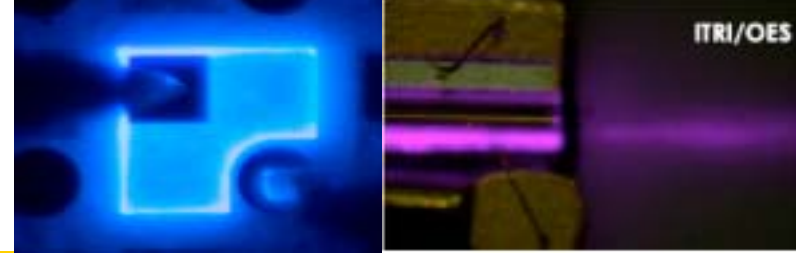
•封裝製作：晶粒黏著打線、覆晶黏著、螢光粉塗佈、樹脂選用、高散熱設計、光學設計(能專+技轉業界)

•測試及應用：光強度、效率、色溫、演色性、Lamp、SMD、點矩陣型、集束型、燈板模組及應用(能專)

# Compound Semiconductor

## III-V technologies developing in Taiwan





## GaN Research at ITRI/OES

MOCVD Growth  
AIXTRON 2400G3-HT  
HVPE Growth  
Device Processing  
Device Package  
Measurement

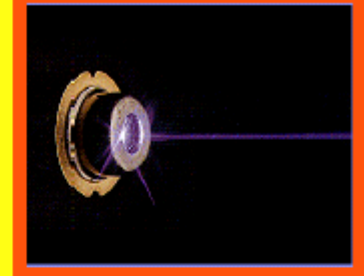
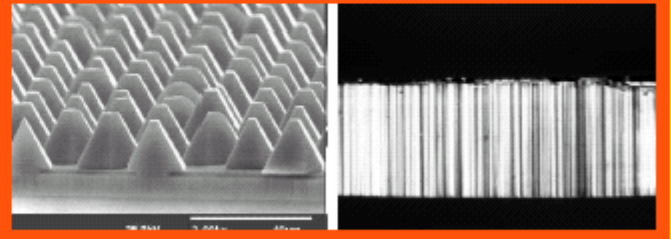
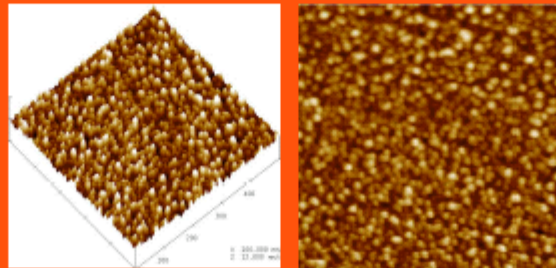
LED MOCVD Growth and Device Fabrication

LED Lighting and Lighting Application

LD MOCVD Growth and Device Fabrication

HVPE Growth GaN Substrate

GaN Quantum Dots





# Comparison of 1W White-LED Lamp



Thickness

5mm

15.7mm

Area

17×17mm<sup>2</sup>

25×25mm<sup>2</sup>

Weight

1.85g

6.14g

# Solid State Lighting Technology

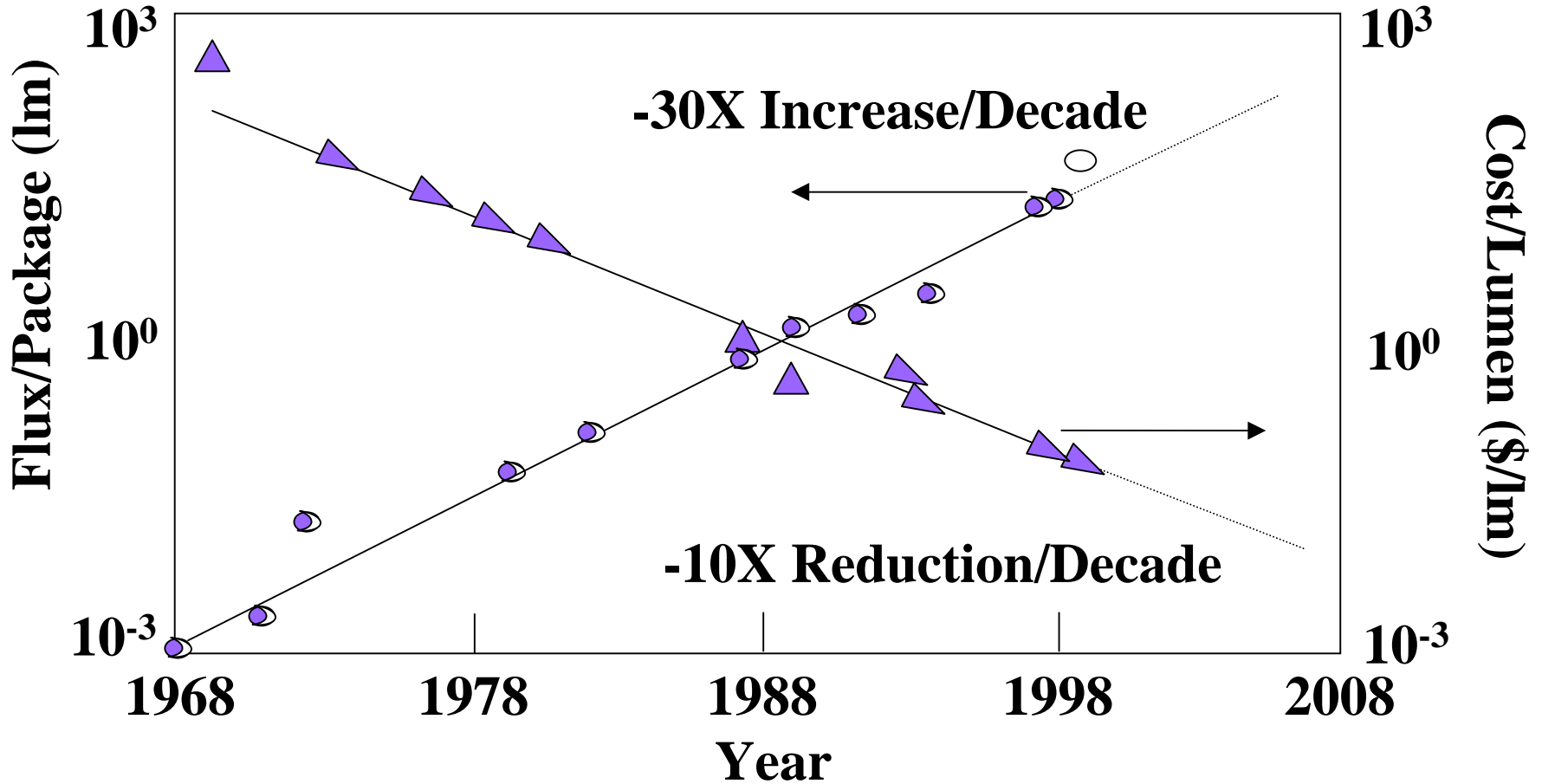
- 發明
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# 商品化白光LED與常用光源之比較

| 光源種類                       | 功率<br>(W) | 外部<br>量子效率<br>(%) | 典型<br>發光效率<br>(lm/W) | 壽命<br>(hrs) |
|----------------------------|-----------|-------------------|----------------------|-------------|
| 白熾燈 Incandescent           | 15        | 5                 | 8                    | 1,000       |
|                            | 100       | 9                 | 15                   | 1,000       |
| 長壽命白熾燈                     | 135       | 7                 | 12                   | 5,000       |
| 鹵素燈                        | 20        | 7                 | 12                   | 3,000       |
|                            | 300       | 14                | 24                   | 3,000       |
| 精緻型鹵素燈 Halogen             | 50        | 7                 | 12                   | 2,500       |
| 精緻型螢光燈(省電燈泡)               | 11        | 17                | 50                   | 10,000      |
| 螢光燈 Fluorescent            | 30        | 27                | 80                   | 20,000      |
| White LED (blue LED + YAG) | 0.07      | 10*               | 30                   | >10,000     |
| White LED (blue LED + R+G) | 0.07      | 18*               | 25                   | >10,000     |

\*不含螢光粉之轉換效率

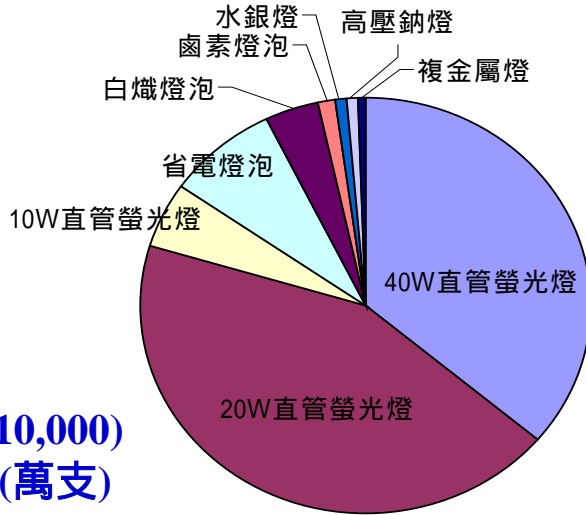
# Performance and cost changes of LED



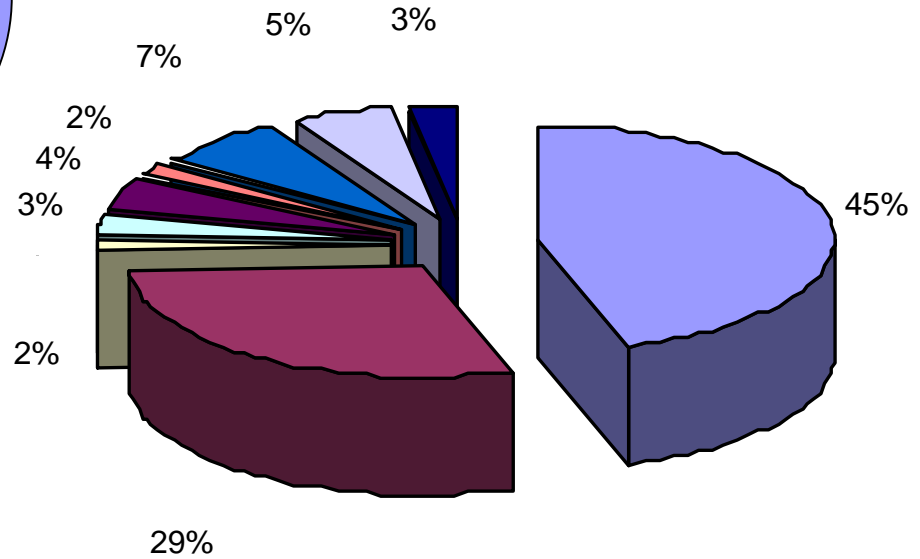
註: 以商業上之紅光LED產品為計算基準, 數據由H.P. 公司之R Haitz提供.

# Types of Lighting Sources used in Taiwan

## 台灣地區各類光源體使用狀況



Energy Consumed by types  
各類光源之耗能比例



Units by types (x10,000)  
各類光源使用量(萬支)

|          | 年消耗量<br>(萬支) | 壽命<br>(小時) | 負載用量<br>(萬支) |
|----------|--------------|------------|--------------|
| 40W直管螢光燈 | 3,600        | 10,000     | 9,400        |
| 20W直管螢光燈 | 3,800        | 7,500      | 11,400       |
| 10W直管螢光燈 | 500          | 7,500      | 1,300        |
| 省電燈泡     | 1,000        | 6,000      | 2,055        |
| 白熾燈泡     | 3,250        | 1,000      | 1,370        |
| 鹵素燈泡     | 400          | 2,500      | 342          |
| 水銀燈      | 80           | 12,000     | 329          |
| 高壓鈉燈     | 70           | 12,000     | 115          |
| 複金屬燈     | 50           | 9,000      | 92           |



資料來源：工研院能資所

# LED for Traffic Lights



# LED vs Incandescence Light bulbs for Traffic Lights Applications in Taiwan

| Light Sources                       | LED                                      | Incandescence Lights                       | Notes                      |
|-------------------------------------|--|--|----------------------------|
| Watt/Bults                          | <b>10W</b> (0.01KW)                      | <b>116W</b> (0.116KW)                      |                            |
| Total Intersections                 | <b>45,000</b>                            | <b>45,000</b>                              |                            |
| Total traffic lights units          | <b>360,000</b> (8 x 45,000)              | <b>360,000</b> (8 x 45,000)                | 8 lights per intersection  |
| Daily electricity consumed (degree) | <b>86,400</b> (0.01 x 360,000 x 24)      | <b>1,002,240</b><br>(0.116 x 360,000 x 24) | 24 hour per day            |
| Yearly electrical energy consumed   | <b>31,536,000</b> (86,400 x 365)         | <b>365,817,600</b> (1,002,240 x 365)       |                            |
| Yearly cost (NTD\$)                 | <b>80,101,440</b><br>(31,536,000 x 2.54) | <b>929,176,704</b><br>(365,817,600 x 2.54) | Cost per unit - NTD \$2.54 |
| Total yearly cost (NTD\$)           | <b>80,100,000 (NTD)</b>                  | <b>929,170,000 (NTD)</b>                   |                            |

- 註：1.根據台電(網路上之資料顯示)，87年度家庭用電每度平均售價：NT\$2.54；  
 2.若使用LED號誌燈,台灣地區每年可省下電力334,281,600度(約3.34億度電力)；  
 3.若使用LED號誌燈,每年實際可省下92,917萬元-8,010萬元=84,907萬元(約NT\$8.5億元)

# Demonstration of White-LED Lighting in ITRI/OES



**Exhibition Room in ITRI/OES**

**50W Halogen Incandescent → 6W LED Lamp**



# Demonstration of White-LED Lighting in ITRI/OES



**Meeting Room in ITRI/OES**

**20W Halogen Incandescent → 9W LED Lamp, Power Saving > 50%**

# Demonstration of **White-LED Lighting** in Taipei Municipal Social Education Hall



**Taipei Municipal Social Education Hall (2F Lobby)**

**20W Halogen Incandescent → 4W LED Lamp, Power Saving : 80%**

**120W PAR38 Bulb → 18W LED Lamp, Power Saving : 85%**

JK Yao Architectural Lighting Design, Taipei, Taiwan

大公設計顧問事務所

- 1999 International Lighting Design Association
  - IALD Award of Excellence
- 2003 International Lighting Design Association
  - IALD Award of Merit
- 2001 International Lighting Design Association
  - IALD Compendium of Good Practice
- 2002 International Lighting Design Association
  - IALD Annual Award Judge

Image #1  
Building in Daylight and Twilight





LED at Mullion Joint -  
Day and Night

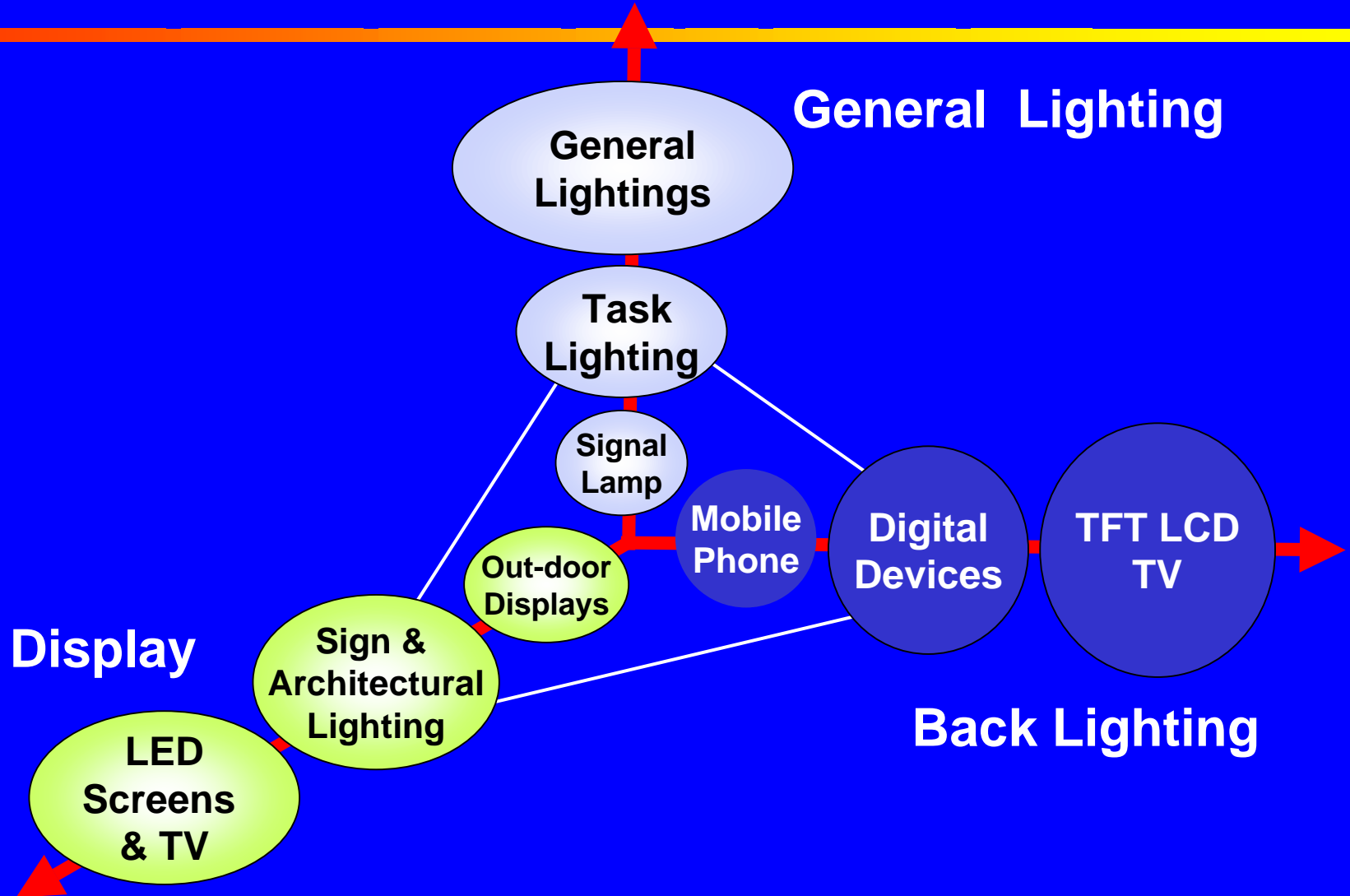


# 應用例-太陽光發電LED路燈



- 內建蓄電池,不需電線架設
- 5年免保養
- 7天內無日照仍可照常使用(假設每天使用10小時)
- 壽命：7萬小時(20年)
- 於無法使用日光燈之寒帶地區還可使用
- 於海岸或河川地區,系統70%浸水仍可正常運作
- 緊急災害期間可正常運作
- 很容易加裝計時器或感測器作減光控制，以延長蓄電池之使用時間

# Directions of LED Application





# LED應用發展趨勢

Display應用  
1980-



儀表煞車燈



移動式看板



戶外看板

特殊照明  
1995-



交通號誌



小尺寸LCD背光



景觀照明



車內外照明

白光照明  
2005



輔助照明



室內景觀照明



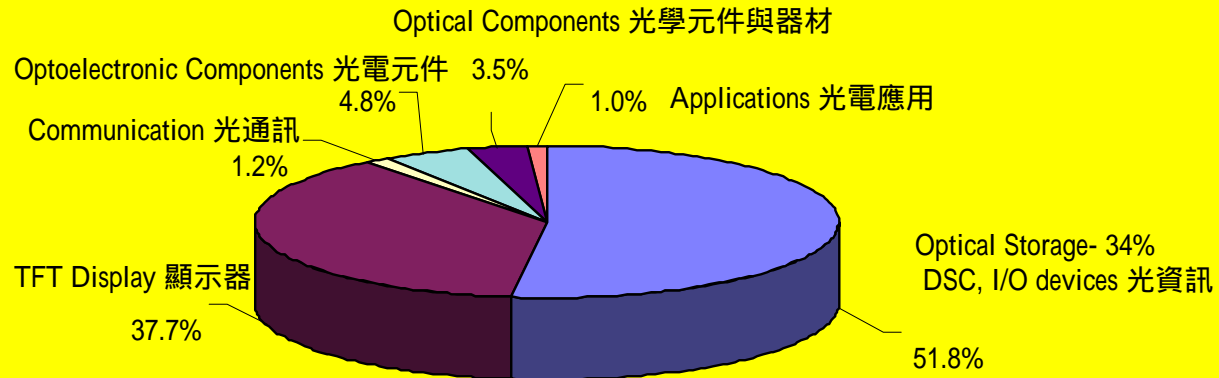
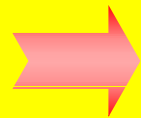
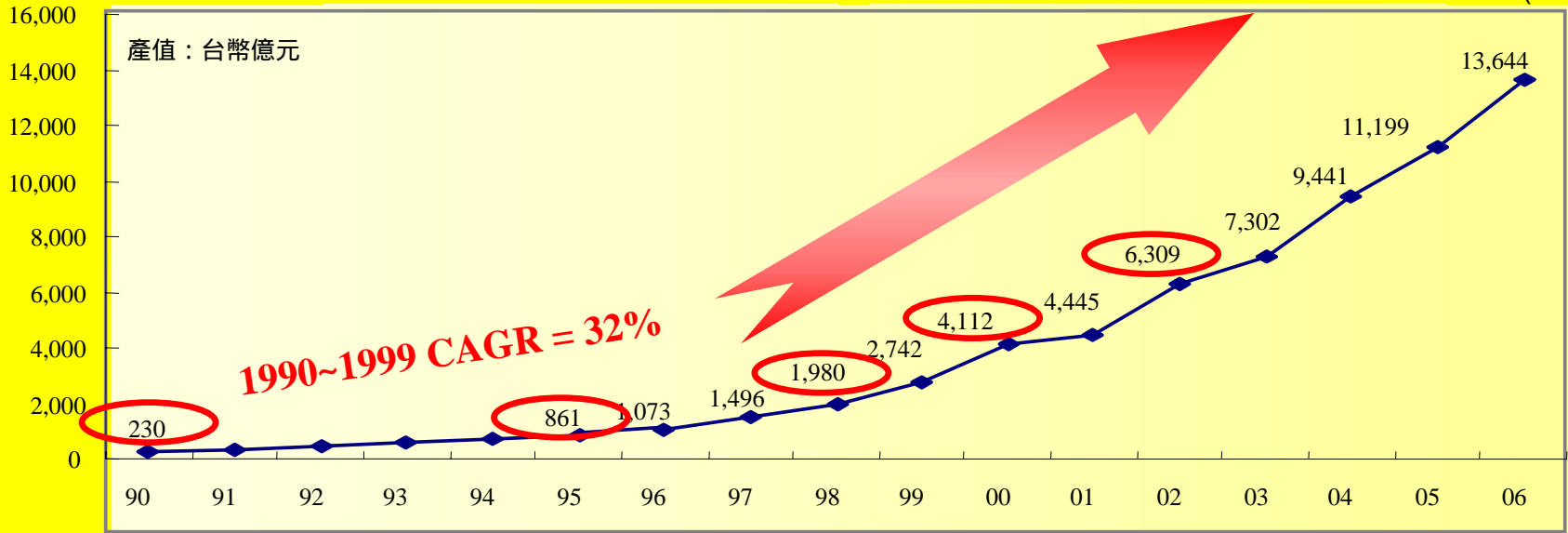
一般照明

# Solid State Lighting Technology

- 發明
- 物理 / 科技
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# Growth of Optoelectronics Industry in Taiwan

Source: ITRI/IEK (2003/01)



2001- Industry revenue USD\$12.4B; 2002 Industry Revenue = USD\$17.8B

## Taiwan's products ranked as top 3 WW in 2002

| Top 1 (15 Items)   | Top 2 (8 Items)  | Top 3 (3 Items)  |
|--|--|--|
| <ul style="list-style-type: none"> <li>• IC foundry</li> <li>• IC Packaging</li> <li>• Mask ROM</li> <li>• CD-R</li> <li>• CD-RW</li> <li>• DVD-ROM</li> <li>• CD-ROM</li> <li>• LCD Monitor</li> <li>• Wireless LAN</li> <li>• ADSL Modem</li> <li>• Cable Modem</li> <li>• NIC</li> <li>• Hub</li> <li>• SOHO Router</li> <li>• Notebook PC</li> </ul> | <ul style="list-style-type: none"> <li>• IC Design</li> <li>• IC Resistor</li> <li>• Large TFT-LCD Module</li> <li>• S&amp;M TFT-LCD Module</li> <li>• LED</li> <li>• Ethernet Switch</li> <li>• Analog Modem</li> <li>• Mother Board</li> </ul> | <ul style="list-style-type: none"> <li>• DRAM</li> <li>• S&amp;M TN/STN</li> <li>• LCD Module</li> <li>• PDP</li> </ul> <p><i>IC - 6 items</i><br/> <i>Optoelectronics - 11</i><br/> <i>Communication - 8</i><br/> <i>Information technology -</i></p> |

Taiwan is one of the leading producers in the world in optoelectronics (USD\$17.8B), electronics & IC (USD\$18.7), communication (USD\$14.2B) and information technology (USD\$21B) - related products

## Semiconductor Lighting Industry Association

Formed 2002/10 by companies of LED and lighting industries to develop and promote the technology, standard and applications of LED for lighting applications. The membership has grown from 30+ to 50+ companies.



# Next Generation Lighting R&D Consortium





2002/9/19 - 11 LED companies formed R&D consortium to develop technologies NT\$ 10M

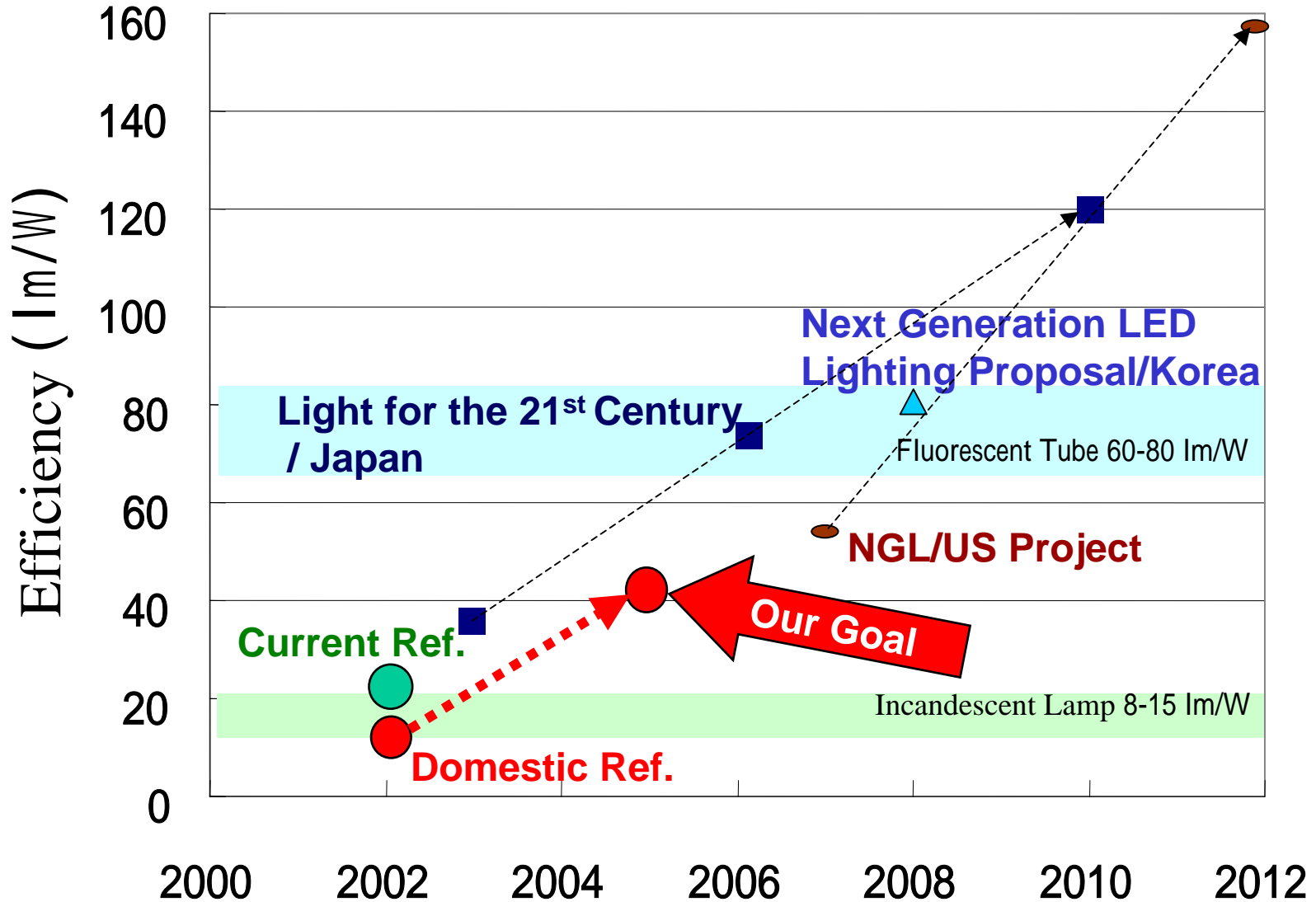
Goal: 40 lumen/W NT\$383M / 2 yrs  
(R&D target: 100 lumen/W)

Phase 1 : 2002 - 2003

Phase 2 : 2 year, 2003/12-2005

|  |  |
|--|--|
| <p>Epitaxy<br/>(Up-stream)</p>                                     |    |
| <p>Processing/Fabrication<br/>(mid-stream)</p>                     |   |
| <p>Packaging/Modules<br/>(Down-stream)</p>                         |  |
| <p>Lamp Design &amp;<br/>Applications<br/>(Lighting companies)</p> |   |

# White LED Efficiency Roadmap



# Future Impacts

## Energy

- Equivalent electric saving to **11B degree**.
- Reduce import energy resource dependency.
- Improve lighting efficiency.

## Economic

- Expedite white LED product development.
- Industry investment: **NT\$2B+**.
- LED revenue **NT\$4B+**.
- Photonic industry revenue to **NT\$40B** by 2005.



High Efficient/Power  
White LED

## Environmental

- CO<sub>2</sub> emission reduction.
- No mercury pollution.
- Reduce waste volume.
- Vibration resistance.

## Industry

- Vertical integration.
- Provide new product for new lighting applications.
- Improve IP protection.



# National Initiatives at China, Korea, Japan and USA

*Y.S.Liu, Industrial Technology Research Institute, Taiwan, ROC*

# National Solid State Lighting Projects in Mainland China

By Dr. Lianghai Chen

## National Project in China (2003-2005)

- “Chinese National Semiconductor Lighting Engineering(SLE)” started from June 17,2003. Investment of SLE is 15 M USD for 2003-2005, and mainly from Government.
- “Semiconductor Lighting Industrialization Developing Technology Project” in Oct. 2003. Looking for 5-10 times budget of SLE, and mainly from Industrial companies.

## National Project in Mainland China (2006 - 2020)

- National stratagem study and consultation report on SSL is underway.
- The target of SSL is :
  - 30% lighting energy saving, the same with electricity generation of TGP(Three Gorges Project)
  - Budget : 5% the investment of TGP
  - Period : 15-20 years, the same with TGP

# Korea National R&D Program on LED

## “Next Generation Growth Engine of Korea” Program ('04-08)

- 10 High Growth Big Industries were Selected (about 2 B\$)

Display Industry: LCD, PDP, **LED**, Organic EL,  
3D, e-Paper

**R&D Fund for LED: about 120 M\$ / 5 years**

Fund for Infra, Training & Education, Standardization &  
Int'l Cooperation will be additionally supported.

### High Growth 10 Large Industries

Digital TV & Broadcast,  
Intelligent Robot,  
Next Generation Semiconductor,

Display,  
Next Generation Car,  
Net Generation Mobile Communication

Intelligent Home Networks,  
Next Generation Battery,

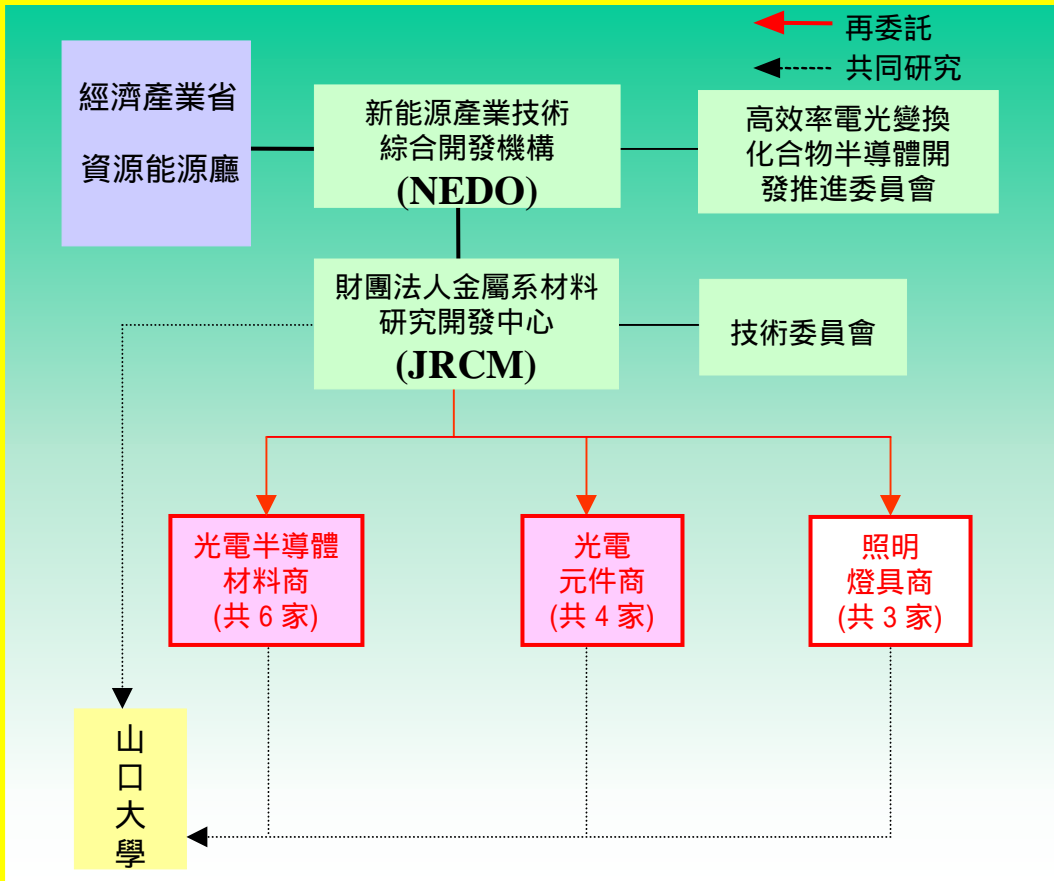
Digital Contents & SW Solutions,  
Bio New Medicine & Chip

# Japan's "Light for the 21 Century"

**Goal : GaN-based Light Source w/120lm/W by 2010**

**Period : 1998 ~ 2002**

**Budget : US\$50M / 5 yrs.**



- **Blue LED + YAG :**  
20% (external QE) at 20mA,  
> 20 lm/W, 6,500K, R=85,  
Life 20,000 hours.

- **UV LED + RGB :**  
24% (external QE) at 20mA,  
Power 16 mW @ 20mA.  
Wavelength = 382 nm

- **Better temperature stability**  
UV LED as compared with  
Blue-based.

# Worldwide National Programs on LED

| Japan  | USA   | Taiwan  | Korea                                       |
|--|---|---|---|
| Light for the 21 <sup>st</sup> century                                 | Next generation lighting initiative (Vision 2020) | Next generation illumination light source project                 | LED and Semiconductor Lighting Korea        |
| 120 lm/W light source  | 200 lm/W light source                             | Infra & Development<br>50 lm/W 2005 (prod.)<br>75 lm/W 2005 (lab) | 80 lm/W (2008)<br>130 lm/W (2013)           |
| Phase I: 98.9~2003.8<br>Phase II: 03.9~08.8                            | Phase I: 2002~2011<br>Phase II: 2011~2020         | Phase I: 02.3~02.8<br>Phase II: 02.8~05.7                         | Phase I: 2004~2008<br>Phase II: 2009-2013   |
| 1 stage: 6 b Yen<br>2 stage: begin in 2004                             | 50M \$/year<br>For 10 years                       | 100M\$ for 2002<br>15M\$/year 2003-2005                           | About 200 M\$/ 5 years                      |
| NEDO+ METI:<br>Yamaguchi Univ (4 Univ. + 13 Companies + 1 Association) | OIDA  | 11 Companies Consortium   | Institute + Univ + Company total Consortium |

# Opportunities for White LED

- Cell phones (1.4B units LEDs)
- Automobiles
- LCD-TV back light (>100M units/year)
  - Mitsubishi announced LED-back light for 17.5” TFT-LCD
- Flashlight for DSC
- PTV light sources



# 大尺寸高彩度LCD電視



**100% NTSC**

**No Mercury**

**70% NTSC**

**3-5% Hg**

***Highly efficient and long lifetime light emitting for better life.***

## 發明:

- 創新
- 創意
- 創造



# Speaker's Biography

**Y.S. Liu**

**Fellow and VP, Industrial Technology Research Institute  
General Director, Optoelectronics & Systems Labs.,**

- **Ph.D. Cornell University**
- **BS, National Taiwan University**
- **Experiences:**
  - **Program Director, DARPA Advanced Research Projects**
  - **Principal Scientist, GE Corporate Research & Development Center**
  - **Adjunct Professors- New York State University, Albany and RPI**
  - **President, Optical Engineer Society, ROC**
  - **Board member, Taiwan Electronics and Electrical Manufacturers Association**
  - **Board member, IEEE, Taiwan chapter**
  - **President, Taiwan Optical Communication Industry Alliance**
  - **President, Solid State Lighting Association, Taiwan**
- **Honors:**
  - **ITRI Fellow**
  - **Fellow of OSA (Optical Society of America)**
  - **Fellow of PSA (Photonic Society of American-Chinese)**
  - **Fellow of PRMS (Asian Pacific Materials Society)**
  - **"50 R&D Stars to Watch", Industry Week**
  - **2003 Recipient of the 10th Tung Yuen Science and Technology Award**

# Thank You

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