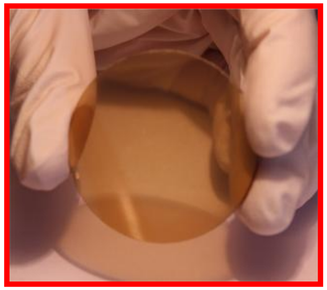
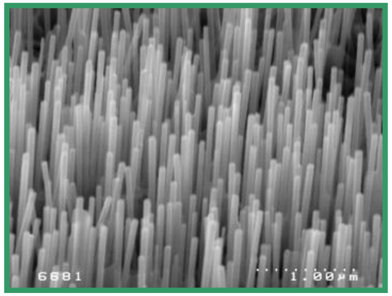
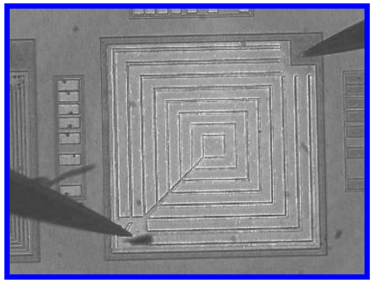
Technologies émergentes pour les LEDs







Alex Lagrange

LETI DOPT

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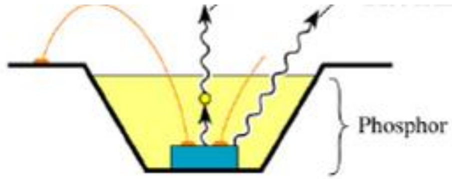
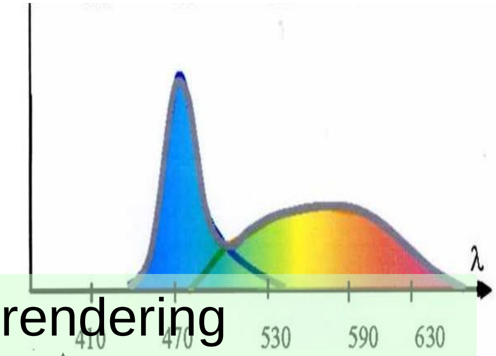
HB-LEDs for general lighting
Current LED device issues



Thermal quenching

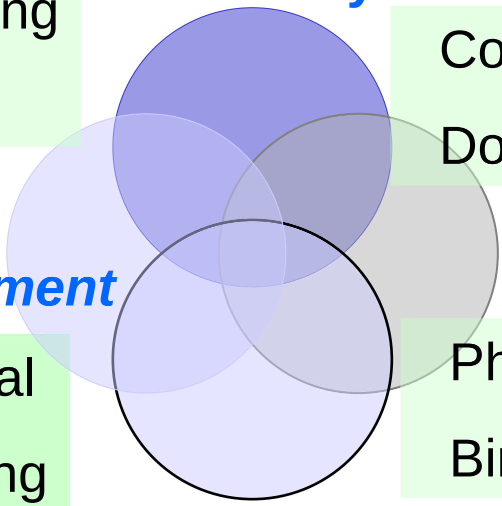
Lifetime

Luminous efficiency



Color rendering

Down-conversion losses



Thermal management

Colorimetry

Substrate removal

Thermal spreading

Phosphor packaging

Binning

Large size **Cost** ***System integration***

Open issues ?

- White generation approach
- Substrate, waferlevel process
- Current density / chip size (droop)

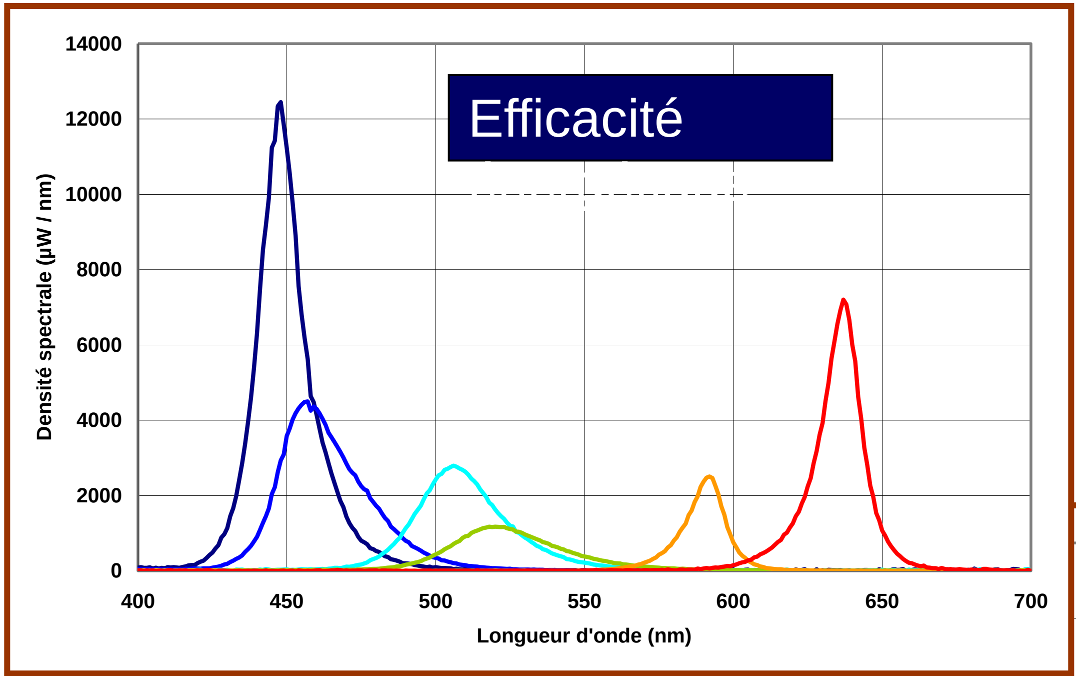
L'efficacité énergétique globale

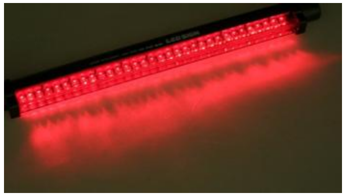
8 rendements qui se multiplient !

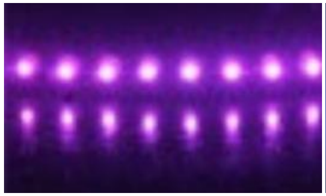
	Rendements élémentaires	2005	2008	Objectif 2015
Alimentation	Driver	85%	85%	92%
LED $T_{jonction}$: 25°C 4100K CRI : 80	Injection électrique	80%	90%	95%
	Quantique interne	60%	80%	90%
	Extraction	50%	80%	90%
	Conversion longueur d'onde	70%	65%	73%
	Diffusion	80%	80%	90%
Luminaire	Thermique	?	85%	95%
	Optique	70%	80%	92%
Global		**8%**	**17%**	**41%**

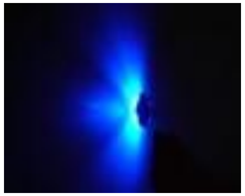
http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/ssl_mypp2009_web.pdf

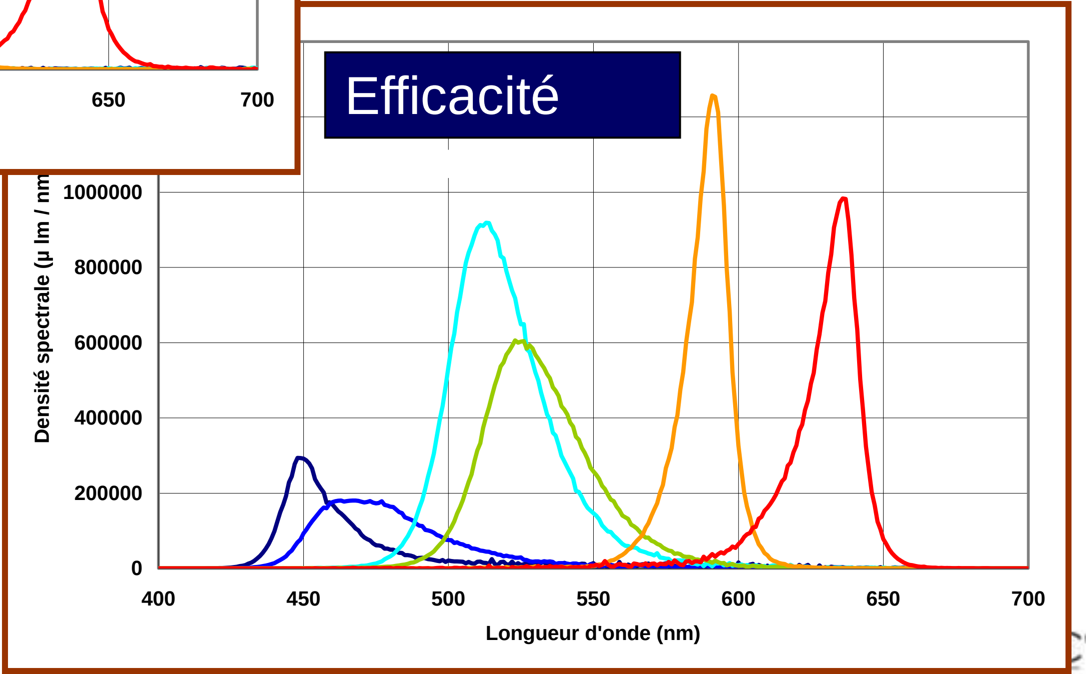
Efficacité lumineuse et efficacité énergétique



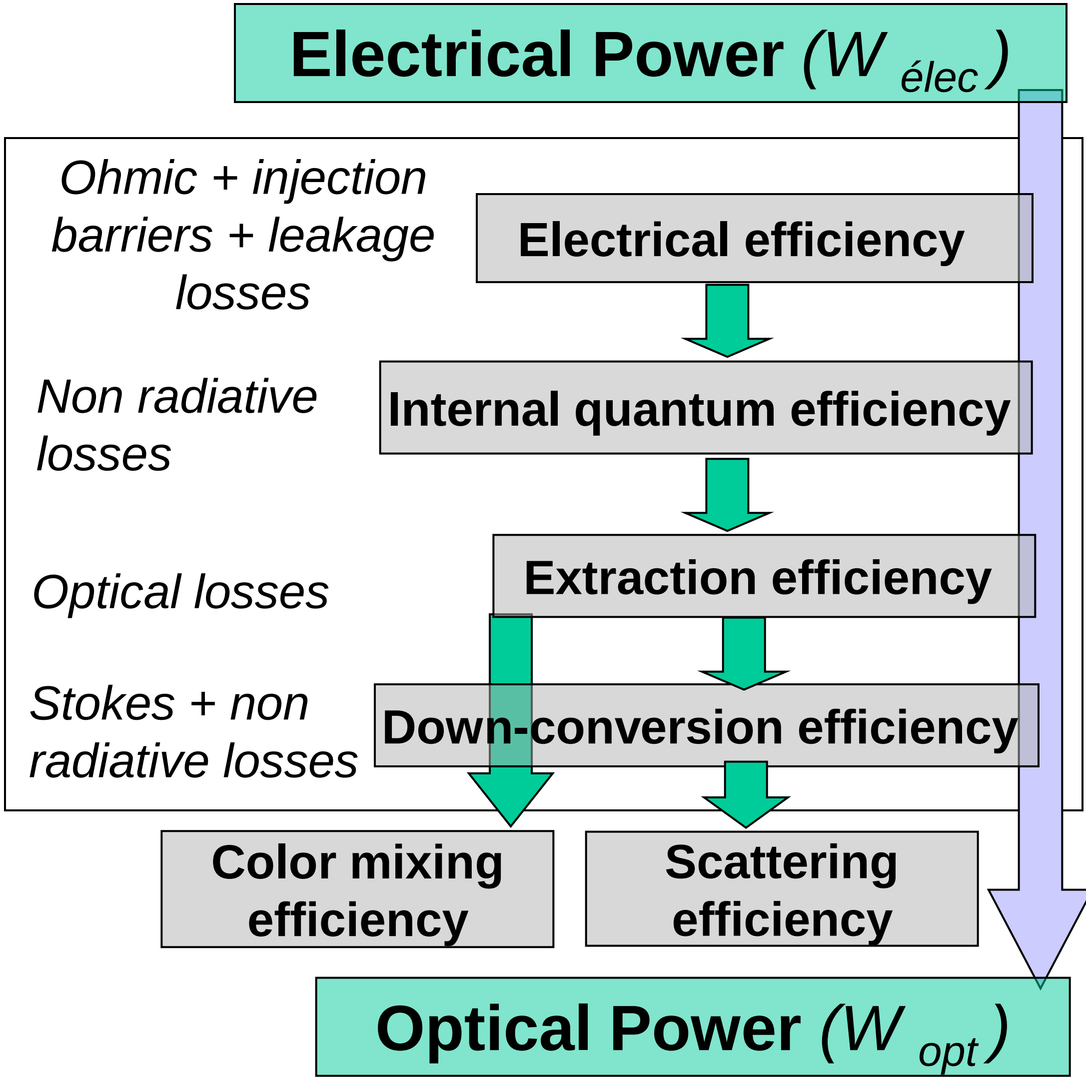








Contributions to LED device power efficiency

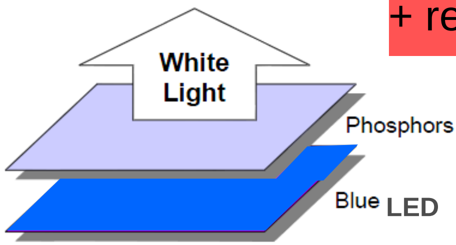
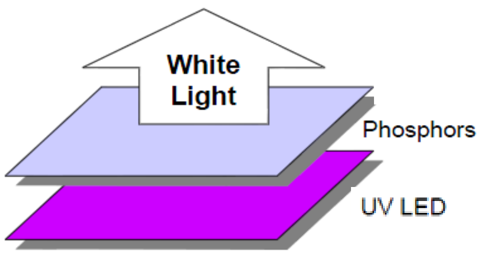
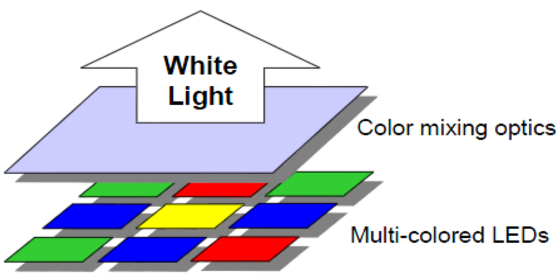
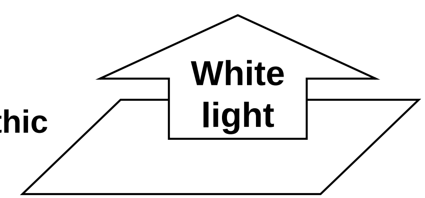


B 450nm	G 540nm	R 610nm	*pc-W*
90%	90%	90%	90 %
80%	**20%**	75%	80 %
80%	80%	**50%**	80 %
			65 %

2008 Products

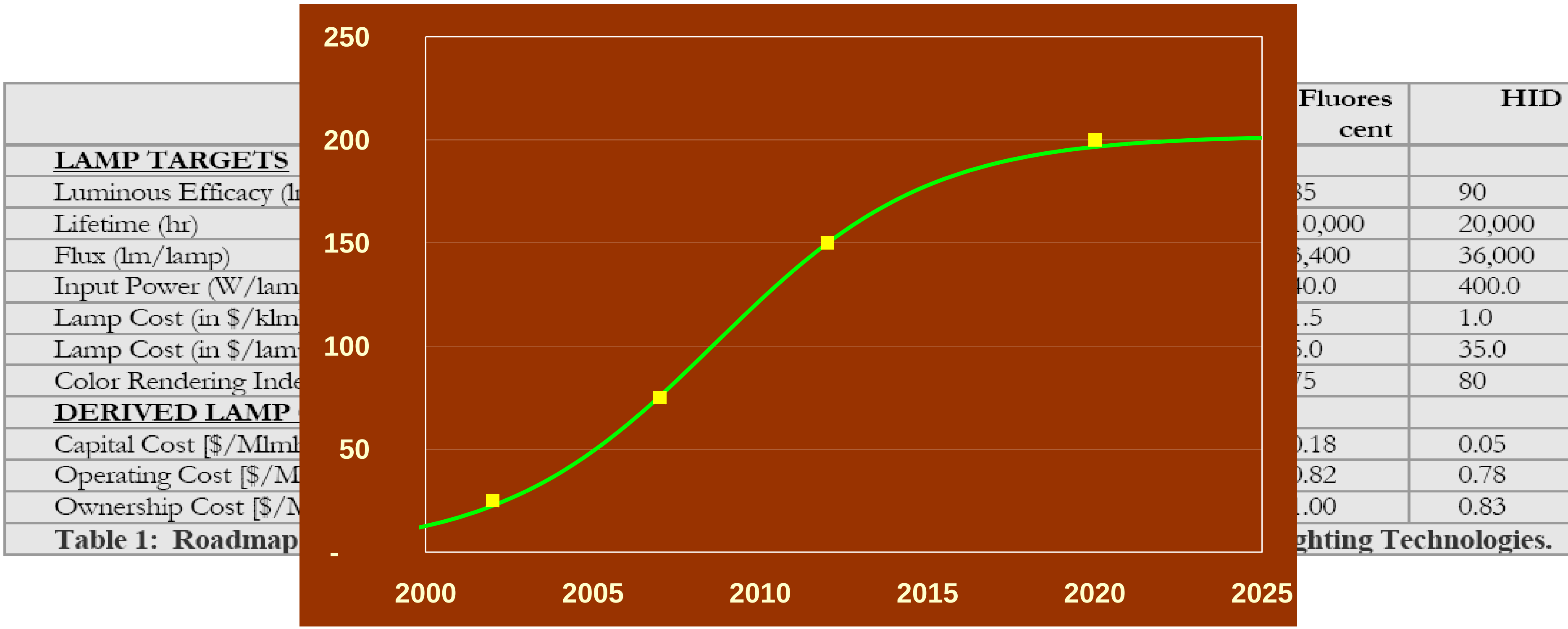
DOE-Multi-Year Program Plan FY'09-FY'15 SSL R&D (Mars 2009)

Which approach for white light generation ?

White approach	Pros	Cons
pc-LED  + red LED	High efficiency blue LED available Mass production	Color binning yield + color drift
pc-LED 	Lower color drift Wider range of phosphors / CRI No color binning	More Stokes loss No efficient n-UV LED available UV compatibility
Color Mixing 	No Stokes loss No phosphor packaging Better CRI / LER	No efficient green LED Color mixing Red AlInGaP drift
Monolithic LED 	No Stokes loss Simple wafer level packaging	Technology ? Color control

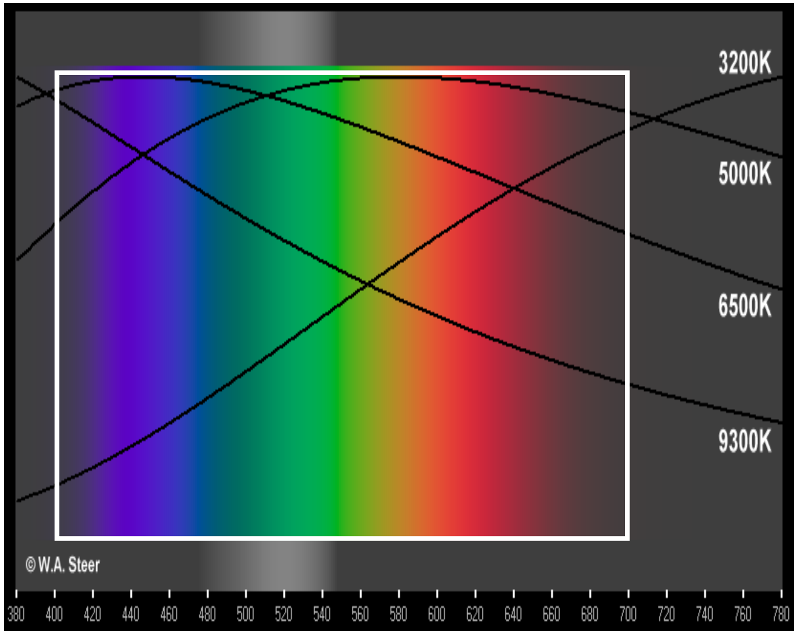
La roadmap de « l'**O**ptoelectronics **I**ndustry **D**evelopment **A**ssociation »

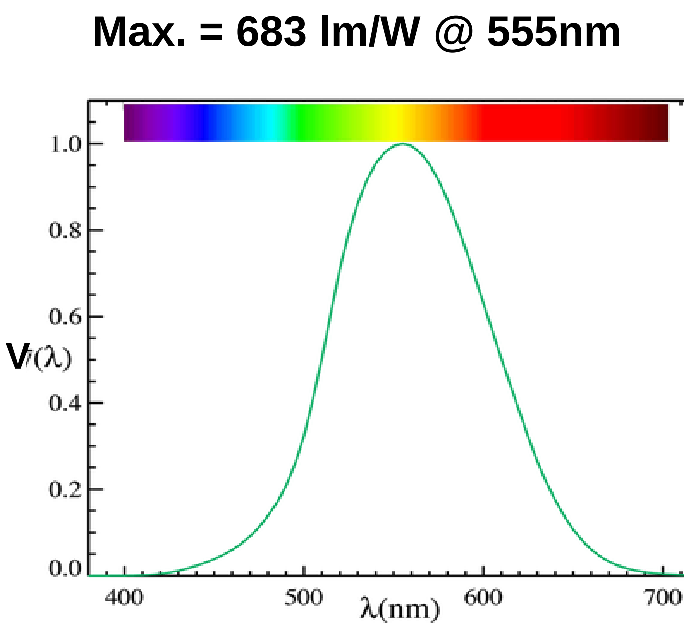
lm/W



Spectral distribution, Luminous efficacy and CRI
Soft spectral variation sources simulation

- « Optimized » black-body *(400-700nm)*





LER ~250 lm/W (2800-6500K) – CRI =100

Simonot & Camelio (Lux, 2009)

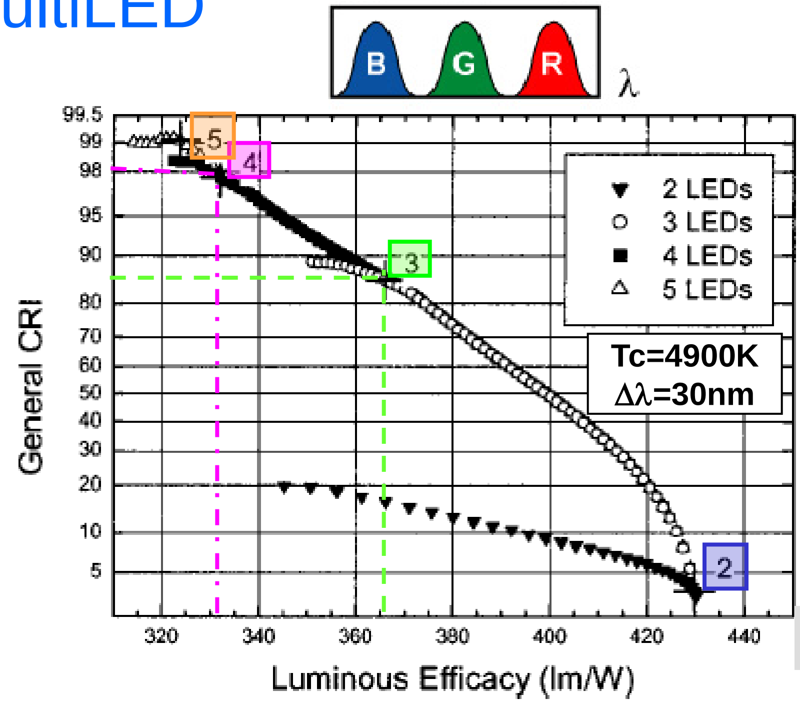
- Equal energy spectrum *(400-700nm)*

LER ~240 lm/W – CRI = 95

➢ Very high CRI but limited luminous efficacy of radiation

Need for efficient green or UV LED

- MultiLED



Zakauska (2002)

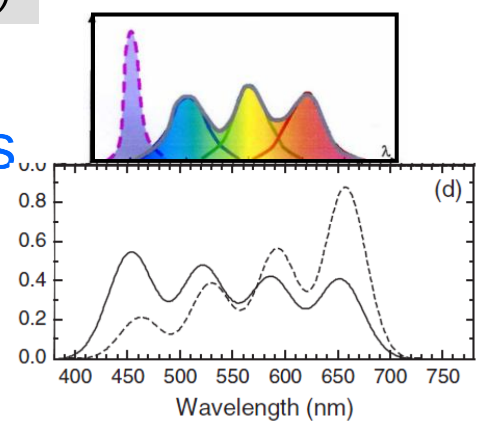
3 LEDs : LER ~300-360 lm/W
CRI =85-93

➢ MultiLED requires efficient **green LEDs**

- Blue or UV LED + 2 to 4 phosphors

LED + multi phosphor
CRI >95 for 3000 or 6500K / 270 lm/W

Zakauska (2008)



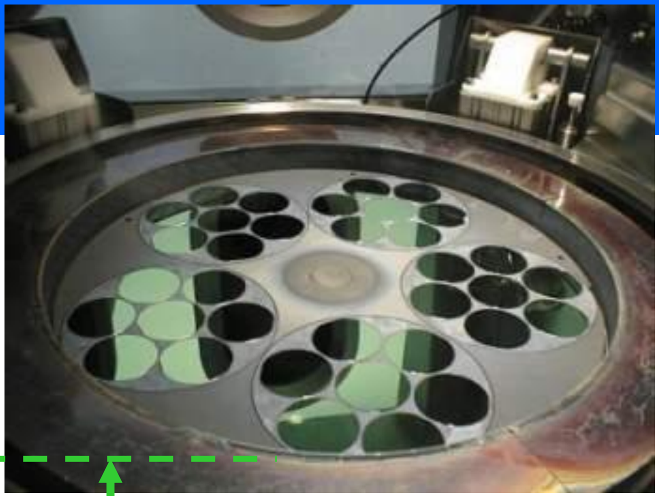
Reachables Values and conditions

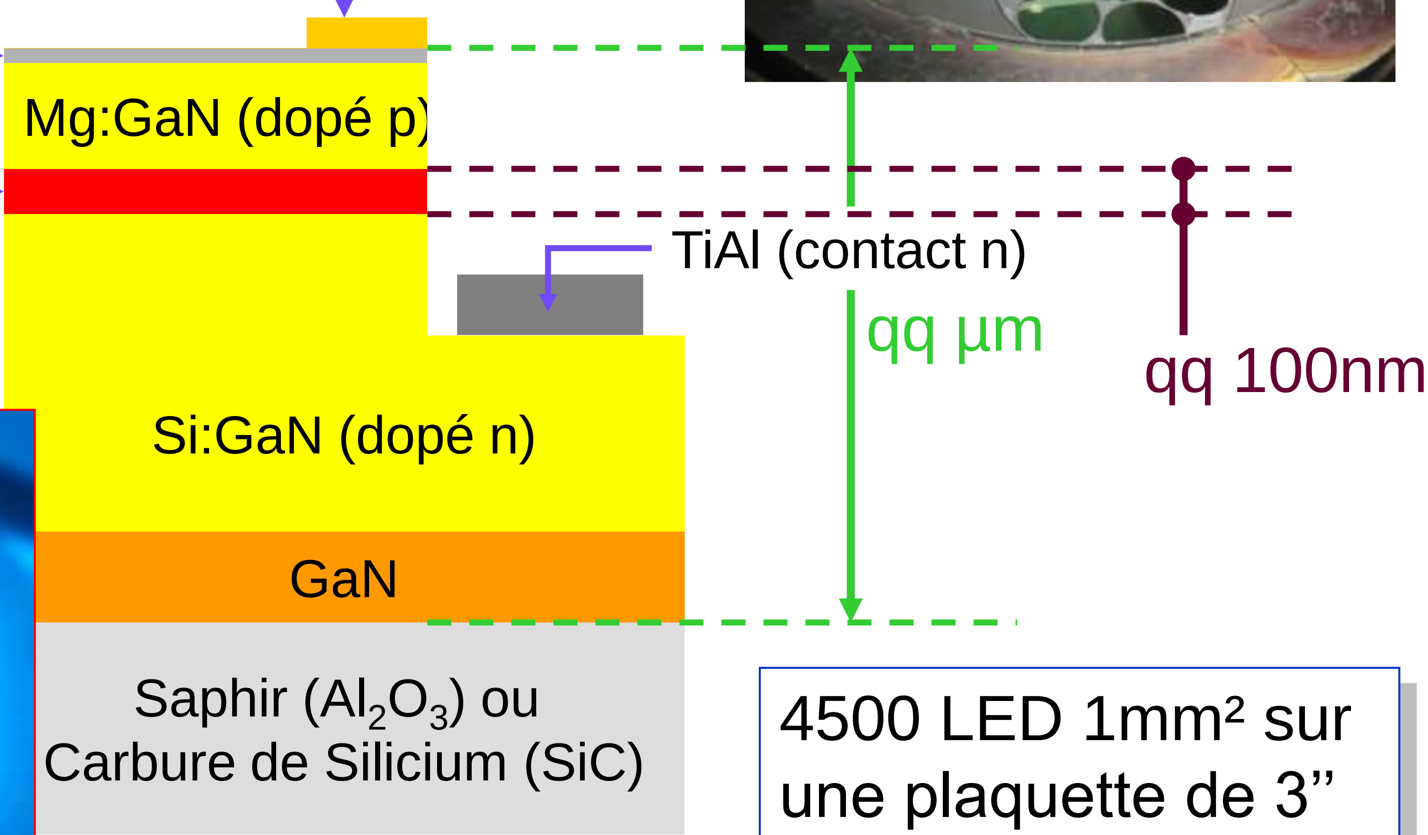
- For a CRI of 90 the maximum efficacy is 408lm/W, 4 colors at 1nm optimised
- Optimised Wavelength , R 614nm Y 573nm G 530nm B 463nm
- Relative Intensity R 1.4 Y 1 G 1 B 0.6
- Red zone is the most sensitive for efficiency
- The reachable value is 70% that means luminous efficiency of 286lm/W
- With low CRI 60 the possible value is 438lm/W

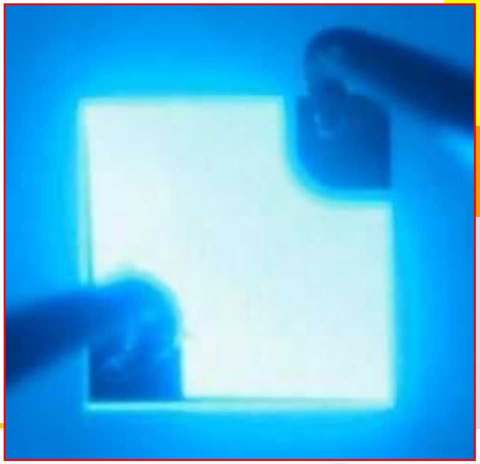
Research challenges to ultra-efficient inorganic solid-state lighting
Laser and photonics Rev 1 N°4 2007

- Technological issues

Héteroépitaxie sur saphir







4500 LED 1mm² sur une plaquette de 3''

Lack of Substrate

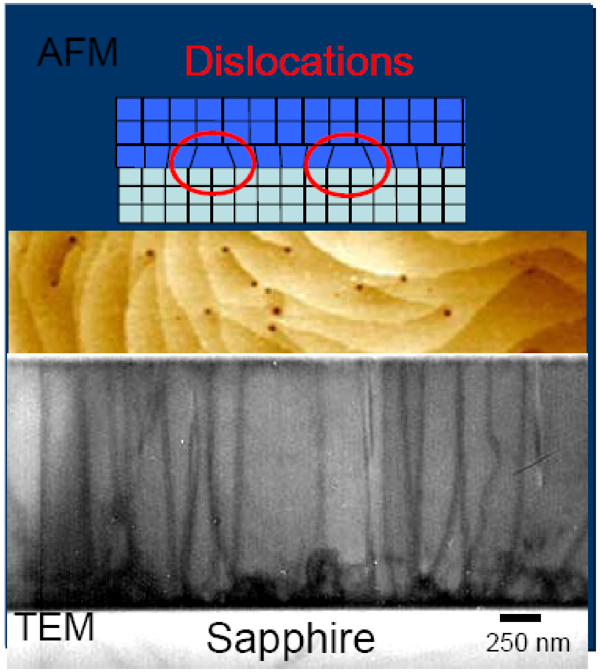
⇨ **growth on Sapphire, Silicon Carbide, Silicon, …**

Very large lattice mismatch

Al_2O_3 (0001):	+16 %
6H-SiC (0001):	-3.5 %
Si (111):	-17 %

High density of dislocations

10^8-10^{10} cm^{-2}



N. Grandjean, EPFL, Forum LED 3/12/2009

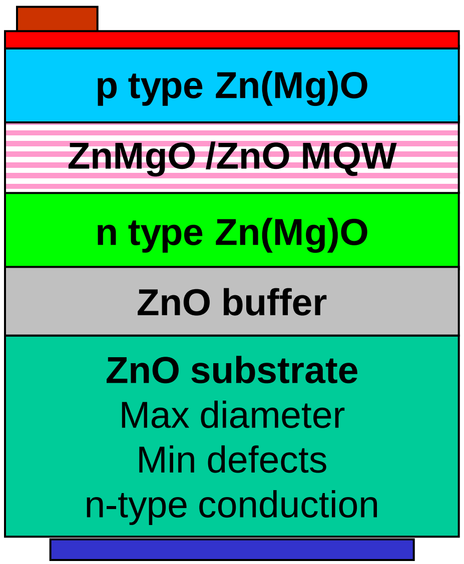
Disruptive technologies and materials

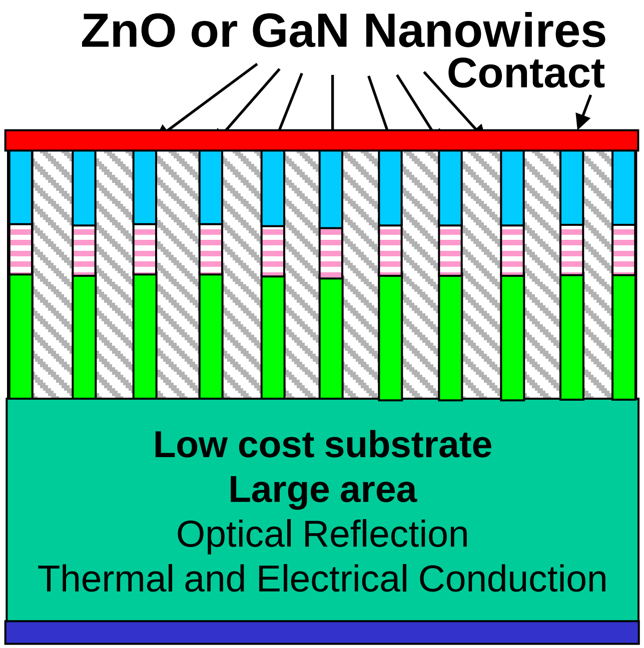
- **Nanowire LEDs**
  - **Green emission**
  - **Silicon substrate**
  - **High light extraction efficiency**
- **ZnO LEDs**
  - **Alternative materials (Zn, O, Mg)**
- **GaN on silicon (not treated here)**
  - Super lattice buffer layers
  - Nanostructures

Front-end selected disruptive approaches

« Full ZnO » planar LED

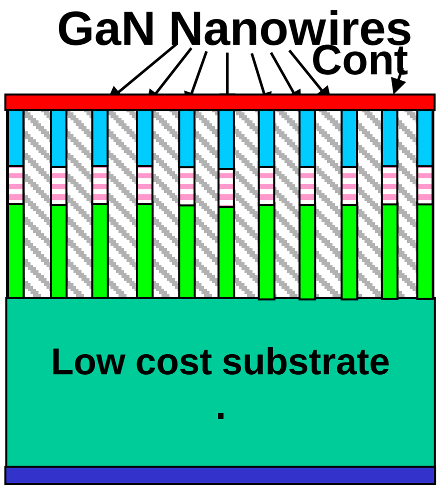
Wide bad gap SC ZnO or GaN Nanowire based LEDs

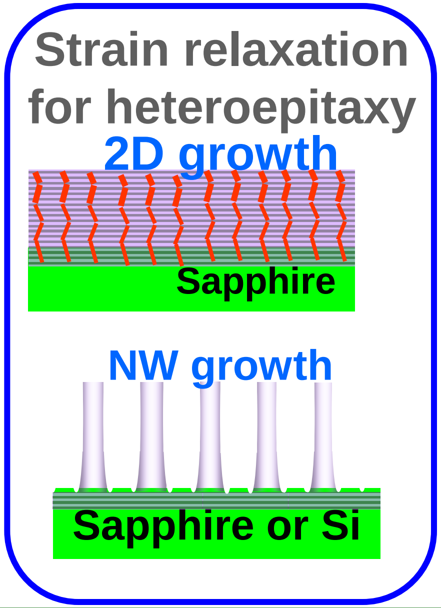




- **Structural defects minimized**
- **Potentially large area substrates**

Nanowire LEDs : motivation



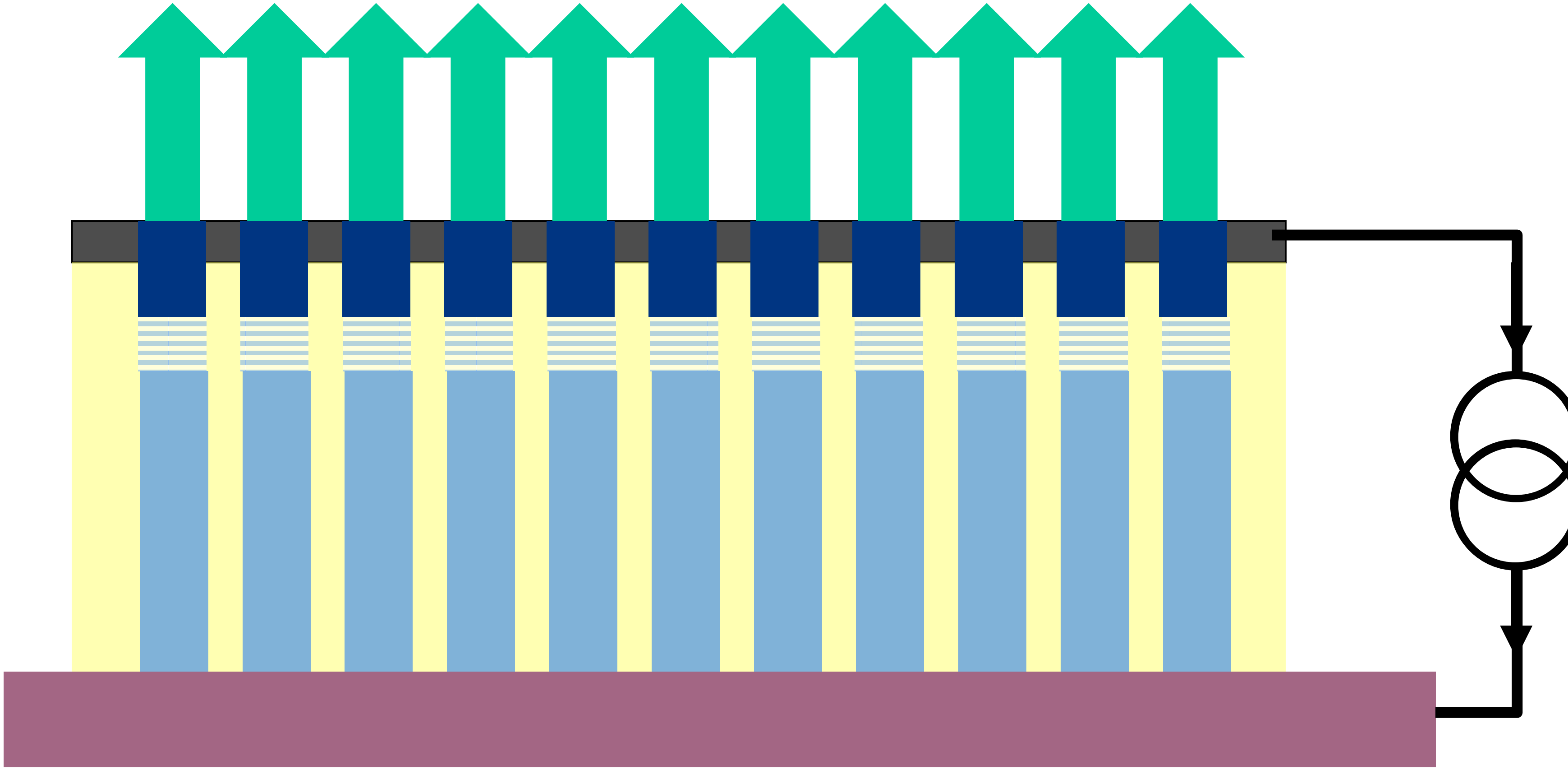


Specific integration for contacting

NW / power density

- Reduced non-radiative defects density
- Lattice and CTE mismatch allowed with substrate
  - Wide range of substrates for growth : large area / low cost
  - Thermally & electrically conductive, reflective, flexible
- Possible higher In concentration in InGaN : color range
- Direct high extraction efficiency without costly process
- Possible non polar core-shell heterostructures

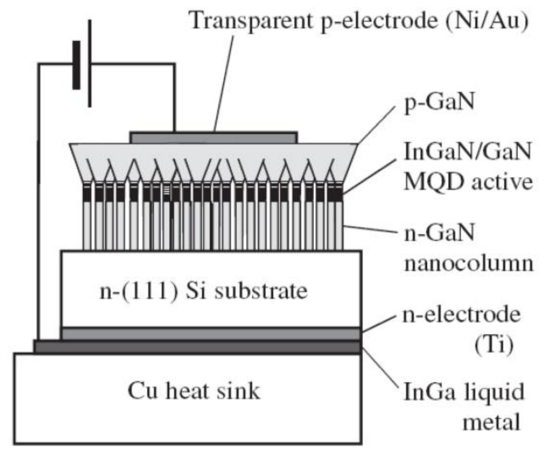
NanoLED specificity



Nanowire LED: State of the Art

✓ First InGaN/GaN MQWs heterostructures in 2004:

- MOVPE *(Kim)*
- MBE *(Kishino)*
  - ✓ EL spectra obtained from blue to red



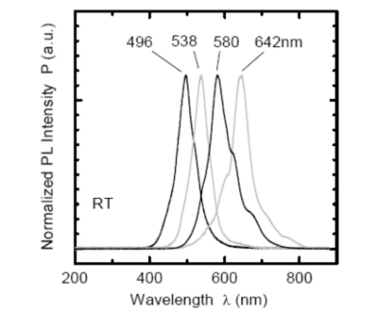
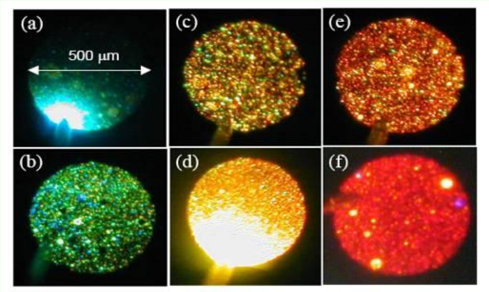


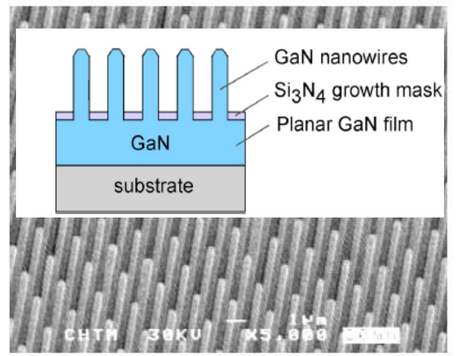
Figure 10: Typical room temperature emission spectra of InGaN MQD nanocolumn LEDs with various emission color of blue (496 nm), green (538 nm), yellow (580 nm) and red (642 nm).



No efficiency data

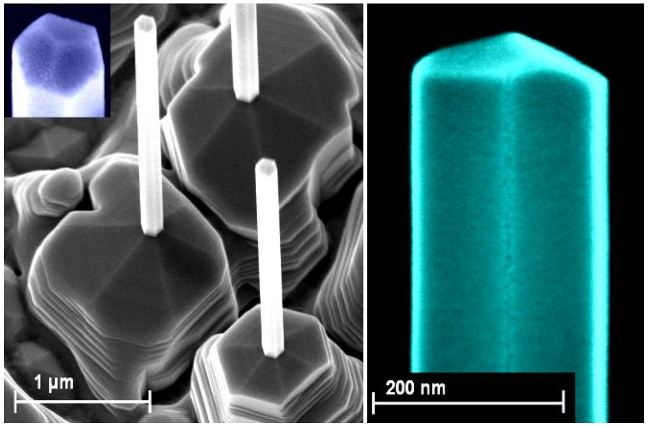
✓ Selective area growth of GaN ordered NW arrays

- p-n GaN homojunction LED MOVPE *(Hersee)*
- GaN/GaN MBE NW *(Kishino)*



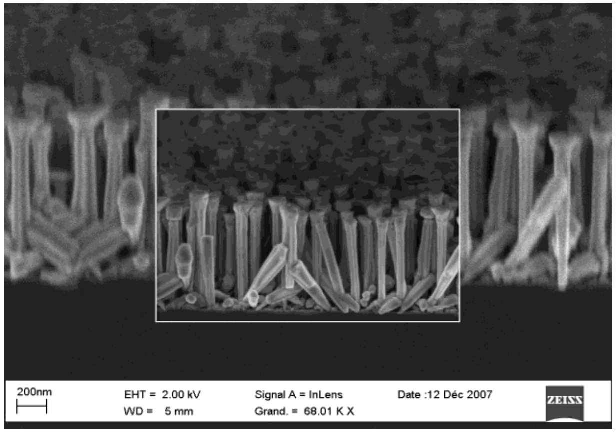
Nanowire LED
development and resuslts at LETI

ZnO



MOCVD-grown ZnO NWs / Al_2O_3

GaN



MBE-grown / Si

« p-i-n » homojunction GaN NWs

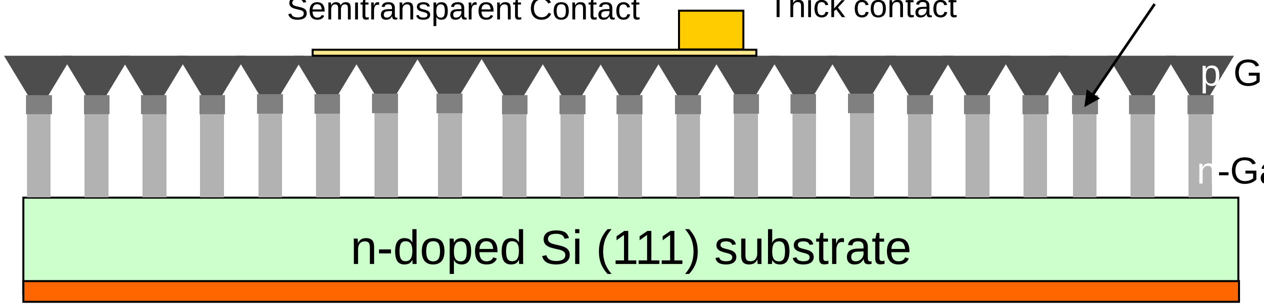
Collaboration CEA/INAC – *B. DAUDIN et al.*

- Growth on metal substrates
- ZnMgO alloys
- ZnO/ZnMgO MQW
- p-doping

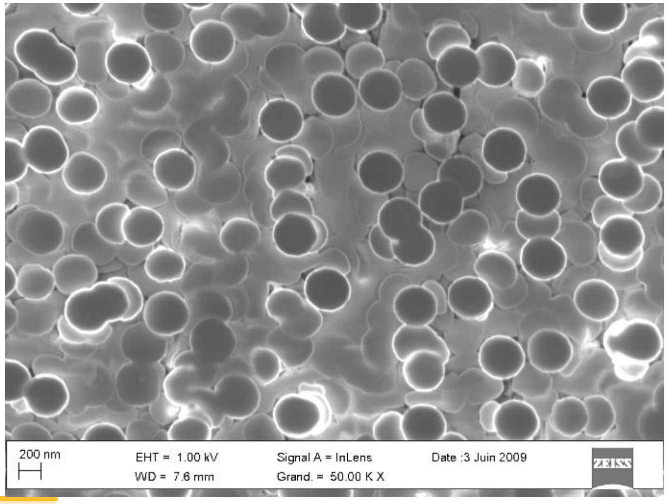
- **MBE grown MQW InGaN/GaN p-i-n heterojunction NWs**
- MOCVD grown GaN NWs

Nanowire LED
ElectroLuminescence in GaN

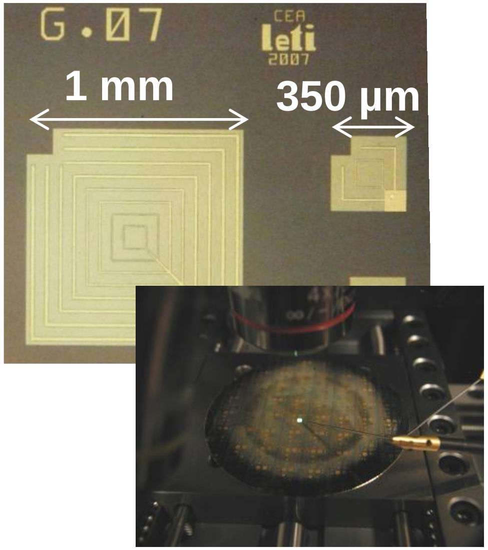
MBE grown GaN nanodiodes



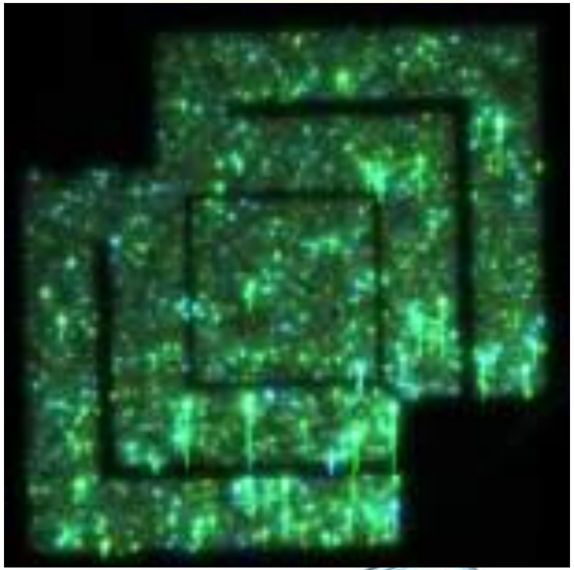
SEM Top view



Microscopic images of LEDs

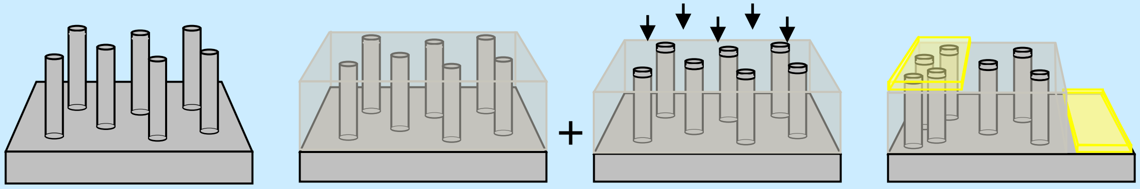


1x1 mm² LED

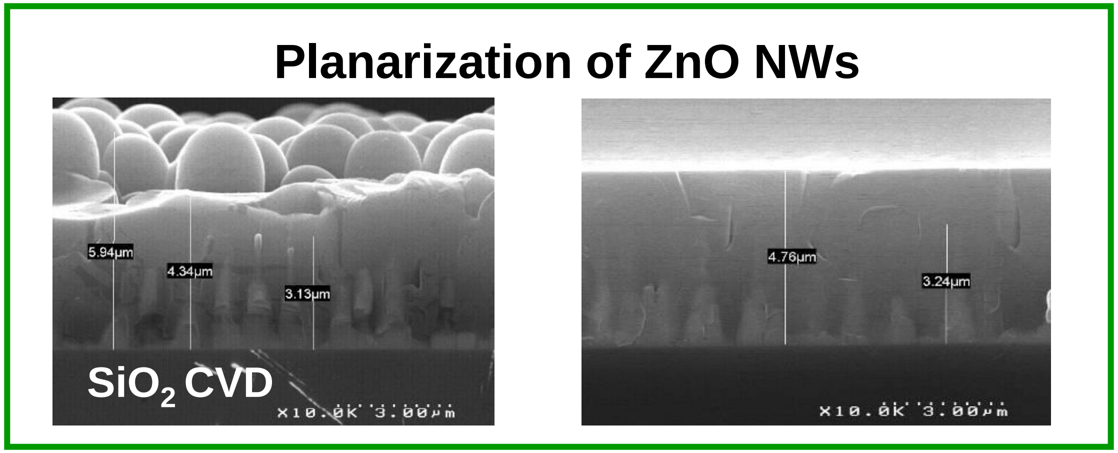


Nanowire LED
ElectroLuminescence in ZnO

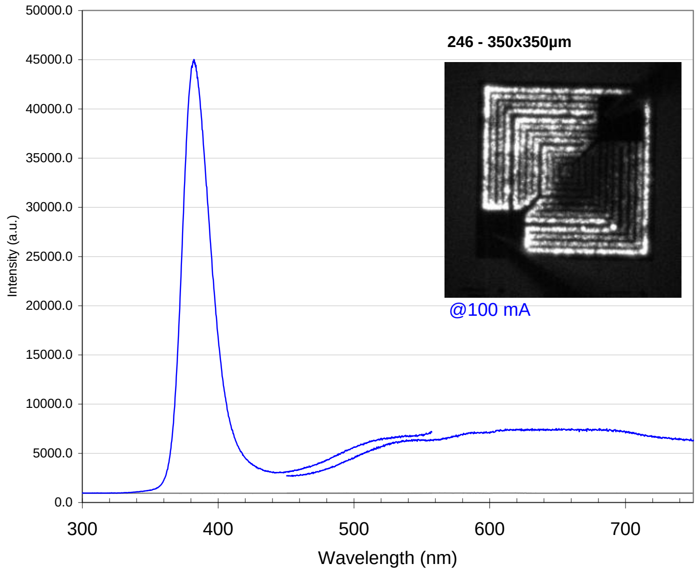
- Planarization by filling + CMP/etching
  - Polymer or spin on glass
  - Mineral CVD SiO2



- Contacting



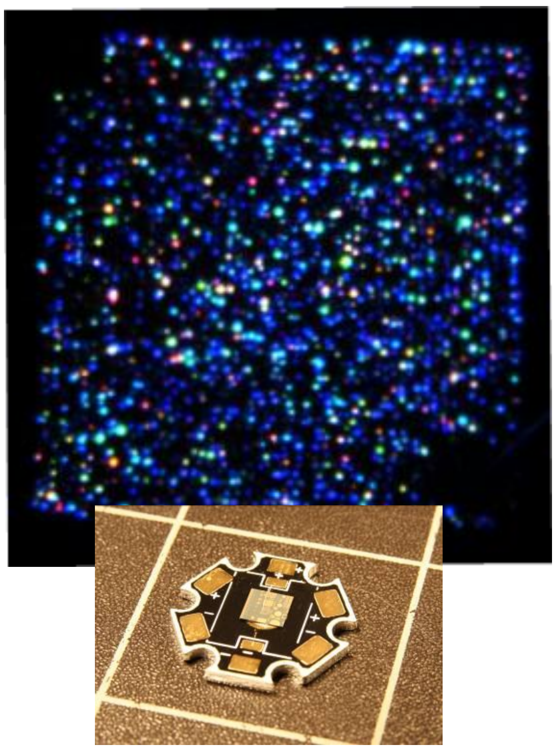
E. ROMAIN-LATU et al. - Nanotechnology 19, 345304 (2008)



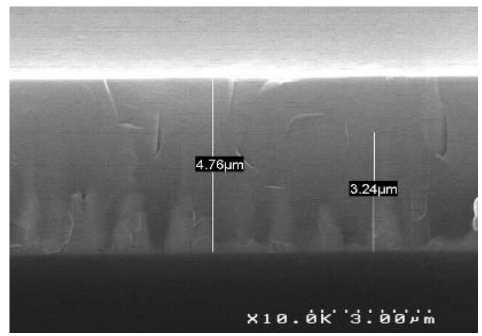
Alternative technologies results

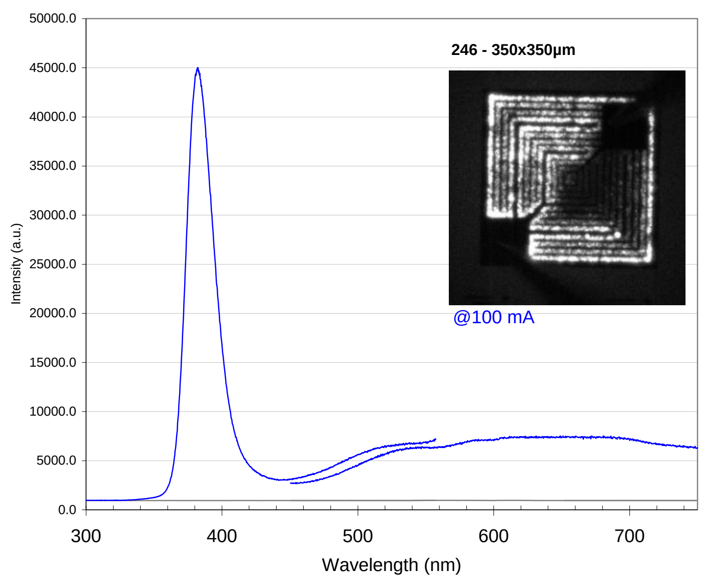
GaN nanowires

1x1 mm² LED

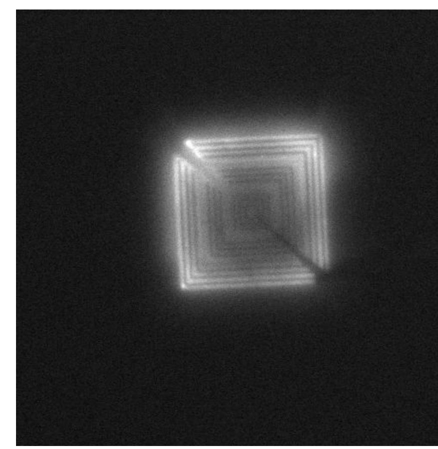


ZnO nanowires

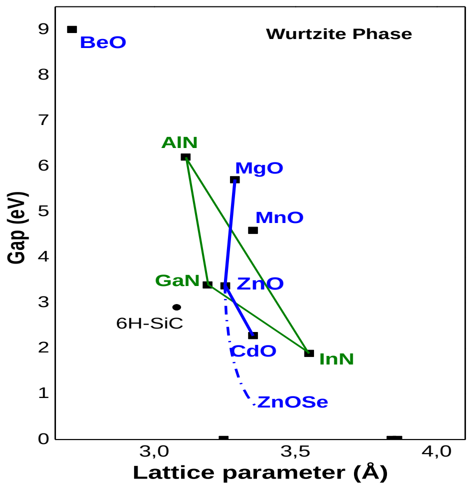


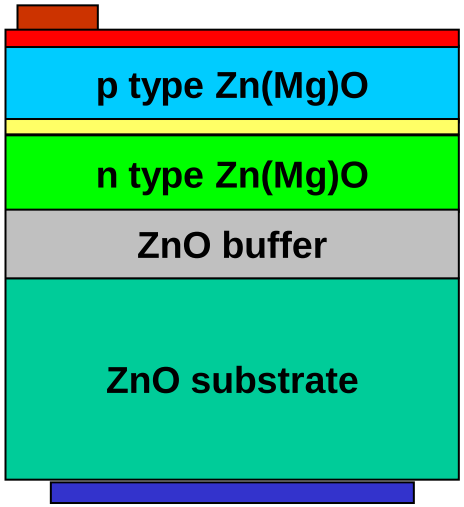


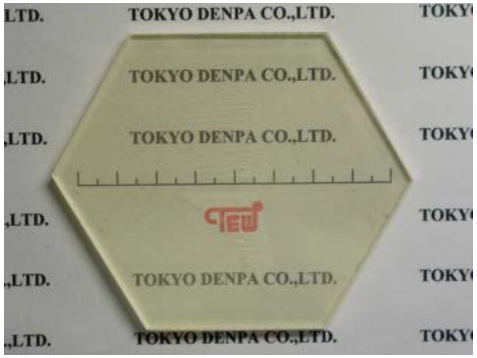
ZnO



ZnO planar LEDs : motivations







3” R&D
2” product
20mm commercial
EPD < 1 E5 / cm²

p-doping issue

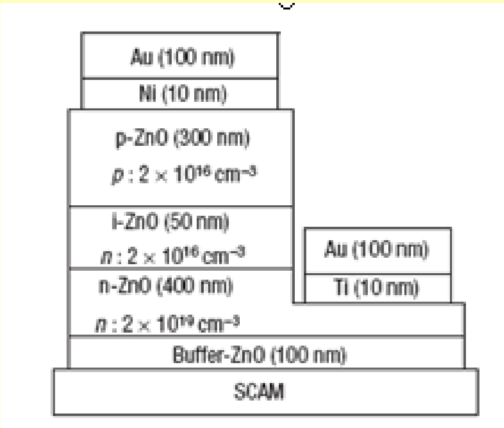
ZnO : alternative substrate for GaN LEDs epitaxy

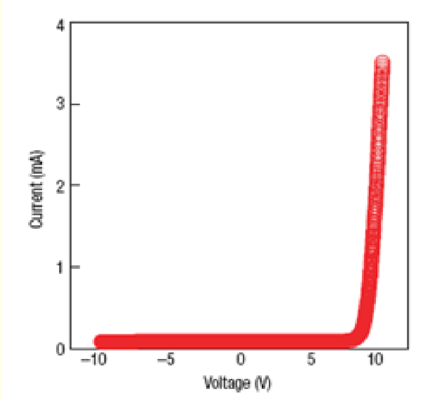
- **Efficient near UV LED for white … with ZnMgO/ZnO**
- **Large high quality ZnO wafer for homoepitaxy**
- **Quasi unlimited raw materials**
- **Non polar heterostructures**
- **Vertical injection**
- **Newcomers welcome**

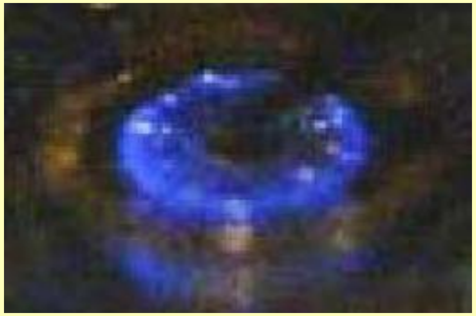
ZnO LEDs : state of the art

❑ **Kawasaki** *(Sendai, 2005) :* **1st ZnO LED** : MBE, p-doped ZnO:N

✓ p-i-n ZnO homojunction on SCAM substrate > **blue EL**





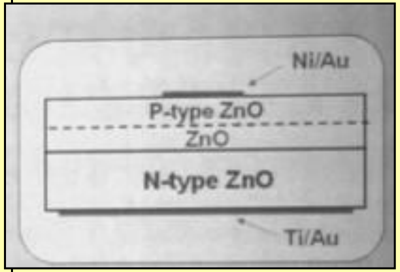


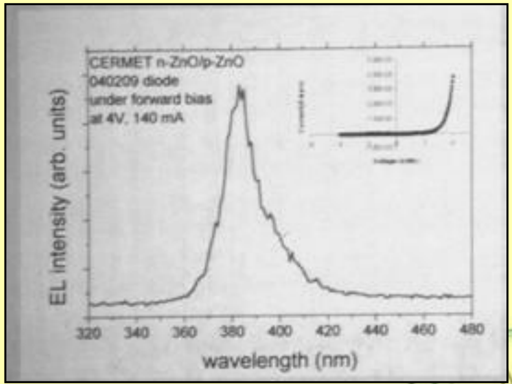
➢ Current development by ***Rohm*** (Japan) on **ZnO substrates**

✓p ZnMgO/ i ZnO / n ZnO / ZnO substrate > **UV electrolum**

❑ **Cermet** (*USA, 2008*) :
MOVPE, p-doped ZnO:N

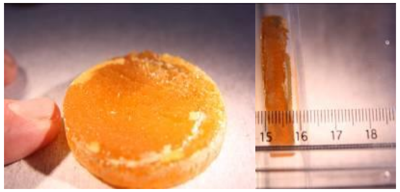
✓ p-n ZnO homojonction
ZnO substrate > **UV EL**

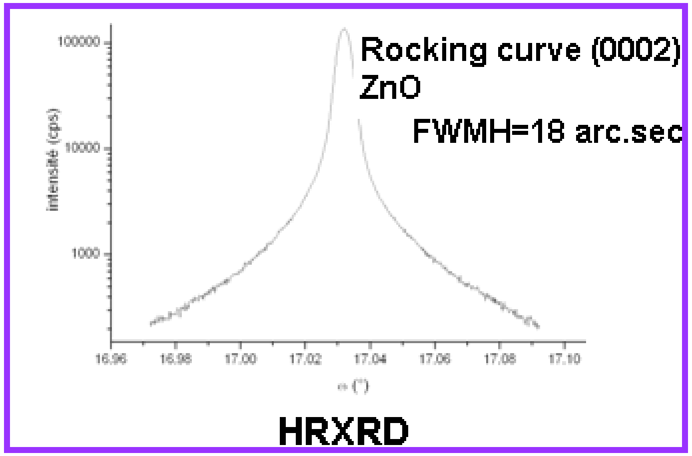




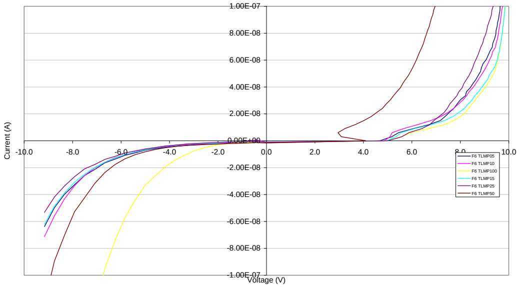
ZnO LEDs : LETI's developments and results

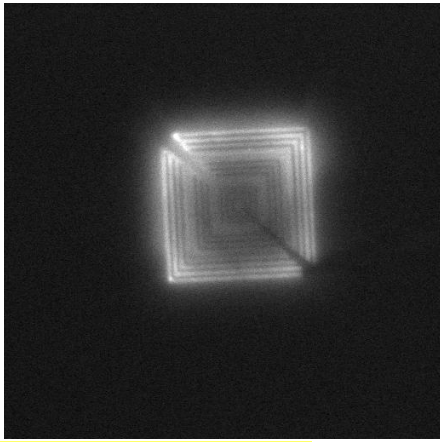
- **Epiready substrate preparation**
- **High structural quality ZnO and ZnMgO layers**
- **p-doping**





ZnO MOVPE grown on c-ZnO substrate





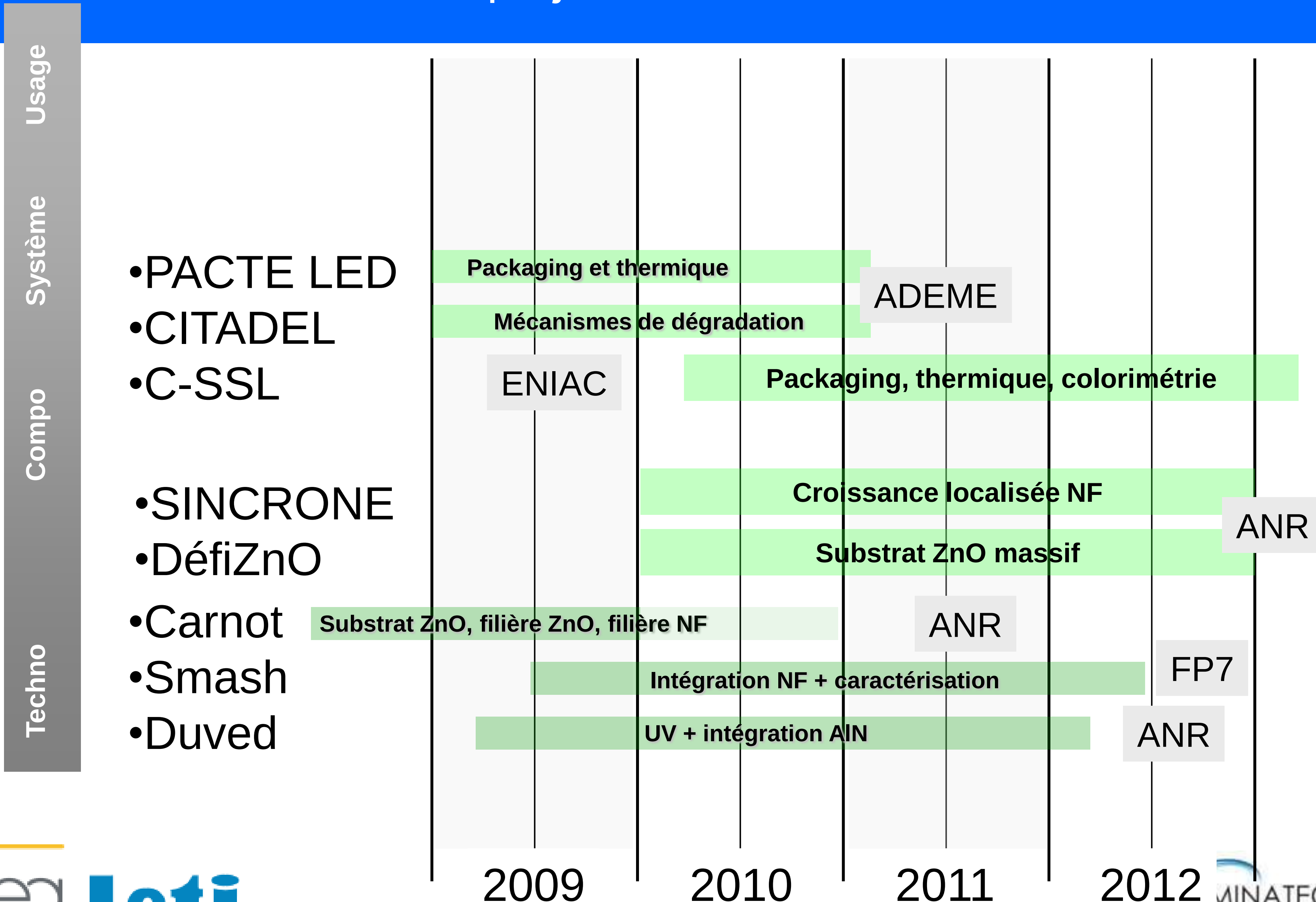
ZnO LED Electro-Luminescence achieved

Conclusion and prospects

- **Internal development**
  - Assesment of our disruptive approaches for high efficiency
  - Lot of room for improvement
    - ZnO LEDs : key p-doping issue
    - GaN NW based LEDs : epitaxy and integration
    - ZnO crystal growth : toward high quality large wafers
- **Driving objectives**
  - **Higher efficiency**
  - **Low cost LED sources**
  - **Direct white emitting diode**

➢ **Towards industrial valorization**

Research projects LETI's involved in



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Academic collaborations

ZnO MOVPE

ZnO charact.

ZnO MBE

GaN NW epitaxy & charact.

Thank you for your attention

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