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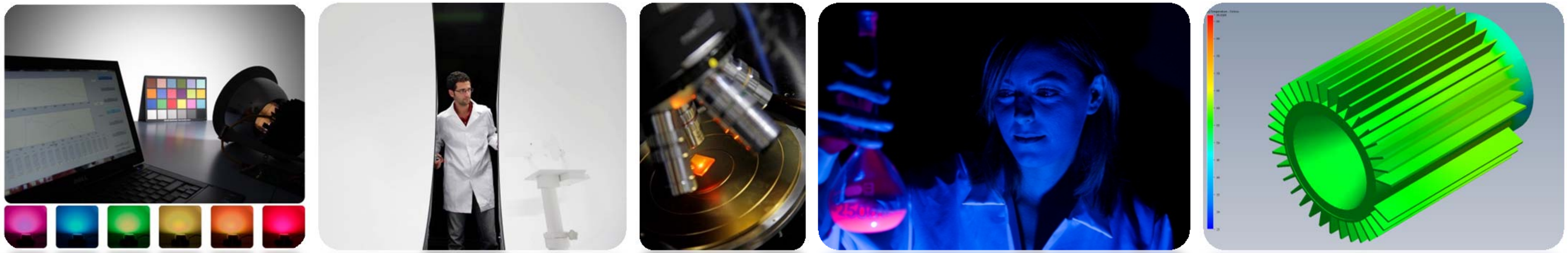


Lighting Group (IREC)

"Materials and efficient lighting"

Dr. Mariano Perálvarez

MAT4ENERGY-2014
Grenoble INP – Minatec, 16th -18th June

Outline

- IREC Lighting Group
- What is light?
- Why LEDs?
- Fronts to achieve efficient lighting
- Materials for efficient and cost-effective lighting
  - Silicon nanocrystals in dielectric matrices
  - PLD matrices with rare earth ions
  - Organic phosphor for wavelength tuning
- Design and optimization of luminaires
  - 3D CAD design
  - CFD simulations of thermal management
  - Raytracing simulations of optical performance
- Intelligent lighting systems
  - Control strategies
  - Spectral reproduction
  - VLC

IREC Lighting group

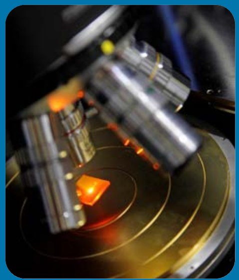
We deal with lighting from the point of view of:

- Research on active materials for LEDs
- Design of LEDs and luminaires
- Implementation of intelligent lighting systems

Our labs:

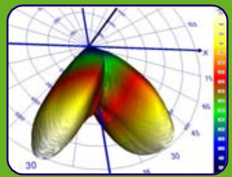
Optoelectronics

"Characterization of luminescent materials"



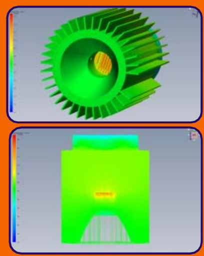
Photometry & colorimetry

"Measurements of all the parameters of light"



Design & Simulations

"Design and optimization of optical an thermal performance"



Control & communication

"Implementation of smart lighting system for energy saving"

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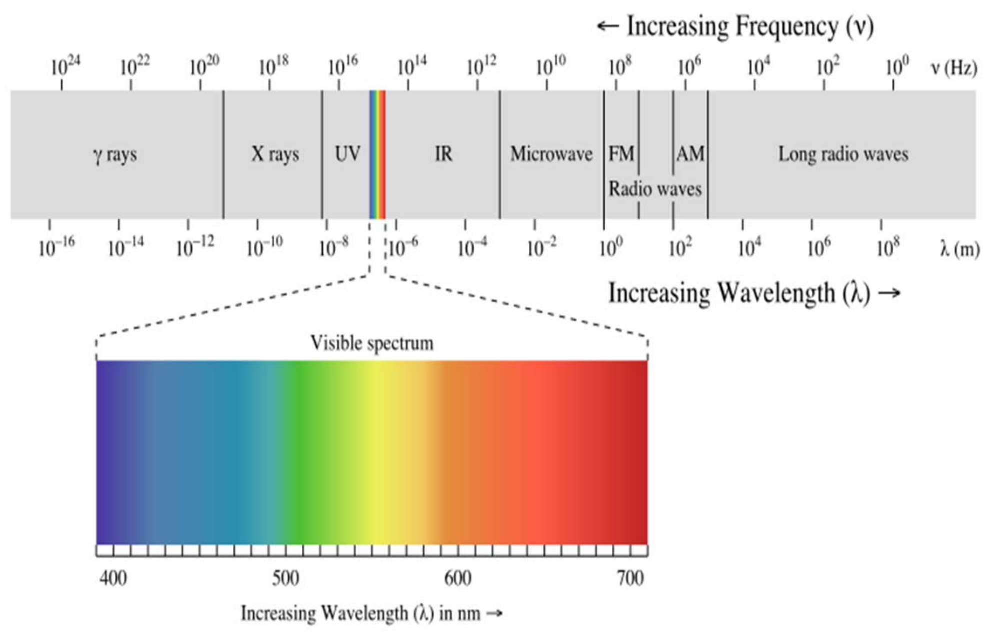
What Is Light?

It is the visible part of the electromagnetic spectrum



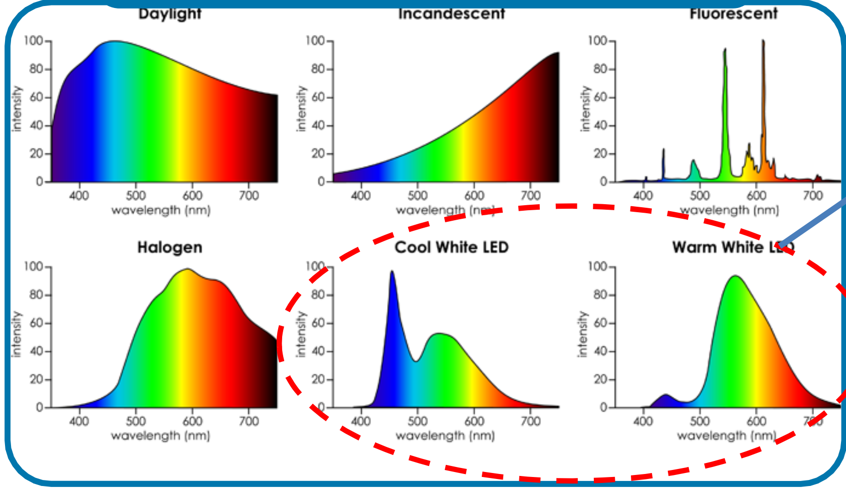
Ranging from 380 to 780 nm

... and can be produced by many different ways...

General lighting

In general lighting we are (mostly) interested in white light

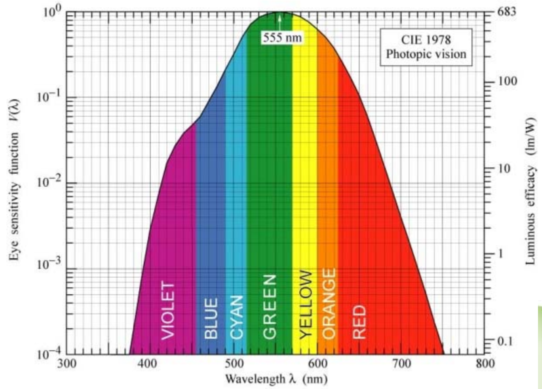
Different approaches are available



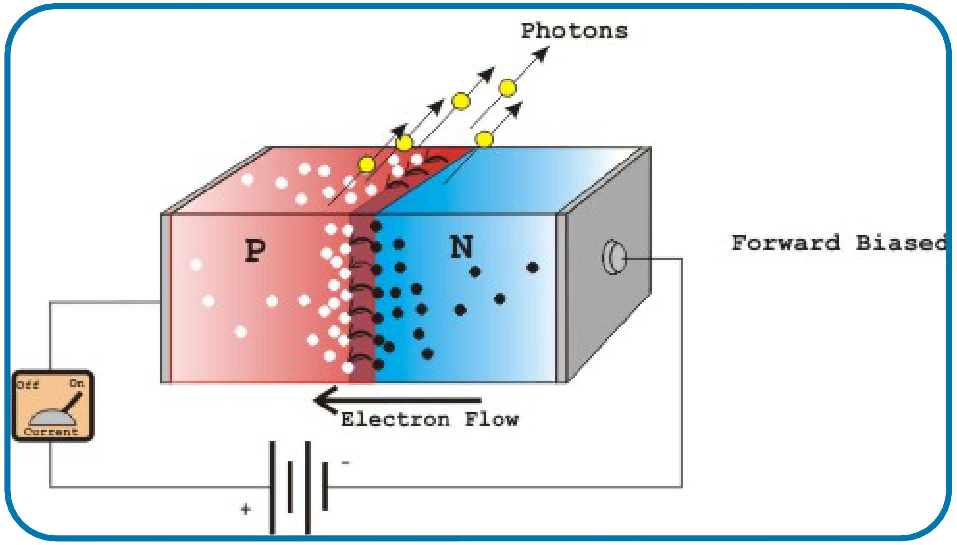
Among those white LED is the most **durable** and **efficient** technology

Product Type	Luminous Efficacy (lm/W)	CCT (K)	L_{70} (hours)
LED A19 Lamp (Warm-White)[1]	94	2700	30,000
LED PAR38 Lamp (Warm-White)[2]	78	3000	50,000
LED Troffer 1' x 4' (Warm-White)[3]	118	3500	75,000
LED High/Low-Bay Fixture (Warm-White)[4]	119	3500	75,000
OLED Luminaire[5]	52	3500	15,000
HID (High Watt) System[6]	115	3100	15,000
Linear Fluorescent System[6]	108	4100	25,000
HID (Low Watt) System[6]	104	3000	15,000
CFL	73	2700	12,000
Halogen	20	2750	8,400
Incandescent	15	2760	1,000

Notes:
1. Based on Philips' L Prize winning A19 lamp.
2. Based on Lighting Facts data label for Cree LRP38-10L-30K lamp.
3. Based on Lighting Facts data label for Cree CS14-40LHE-35K luminaire.
4. Based on Lighting Facts data label for Cree CS18-80LHE-35K luminaire.
5. Based on Acuity Brands luminaires.
6. Includes ballast losses.



What is a LED?



III-V PN-junction

Forward biasing

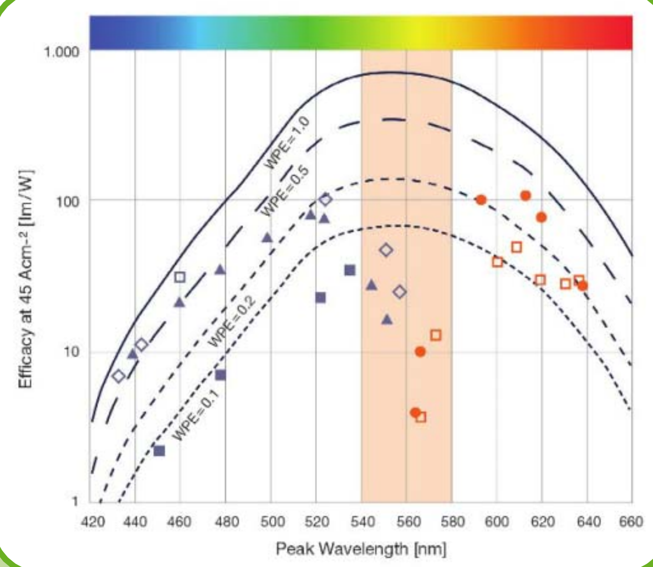
Electron hole recombination

Monochromatic photon emission
(bandgap energy)

Two technologies available:

- **InGaN** (violet to green)
- **AlInGaP** (yellow to red)

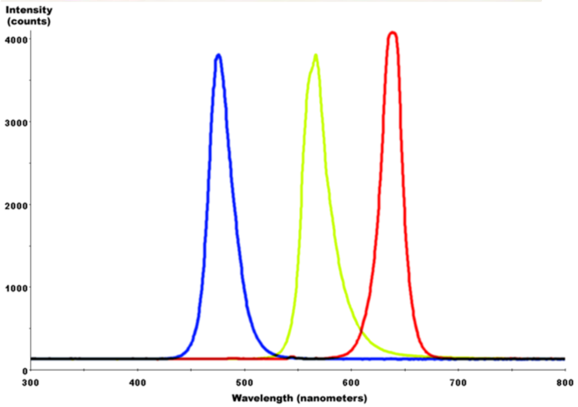
Green gap (540 - 580 nm)



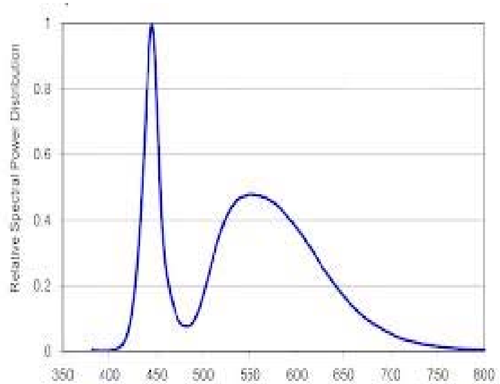
White LED

To obtain white light from monochromatic LEDs there are two approaches

RGB (multiple LEDs)



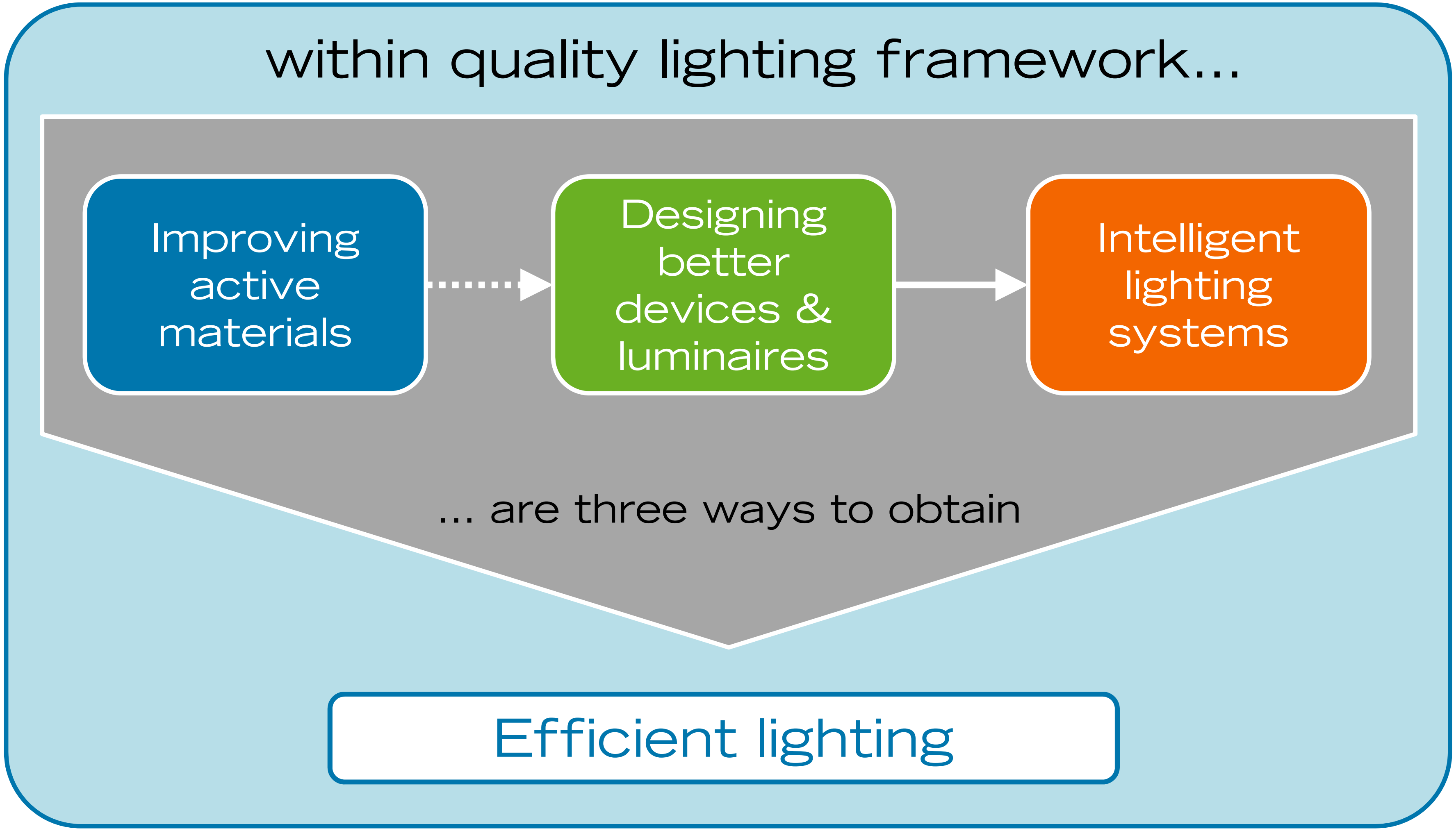
Phosphor converted



Deficiencies to be solved in conventional LEDs...

- **Green gap**
- **III-V materials cost** (ballast the deployment of advanced photonics applications)
- **Thermal management** (overheating leads to shorter device lifetime and color variation)
- **Light extraction** (most of light generated at the junction is lost by total internal reflection)
- **Low integrability** on photonics systems (lattice mismatch)
- **Expensive rare earth based phosphors**

IREC fronts to achieve efficient lighting



Materials for efficient and sustainable lighting

At material level three lines are followed:

Si-nanocrystals in dielectric matrices

Focus on:

- Reducing fabrication cost by compared to mainstream III-V technology"
- Higher photonic integrability

Rare-earth in dielectric matrices fabricated by PLD

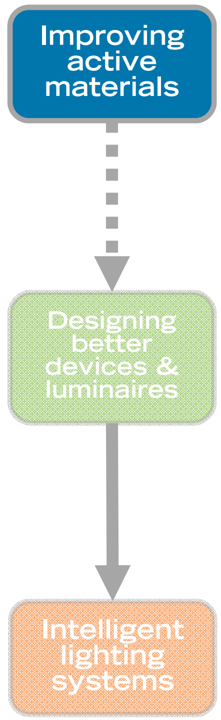
Focus on:

- Reducing fabrication cost
- Improving light extraction
- Providing green wavelengths

Phosphors for wavelength tuning

Focus on:

- Incorporating efficient green emission to III-V technology
- Reducing cost of expensive rare-earth based phosphors



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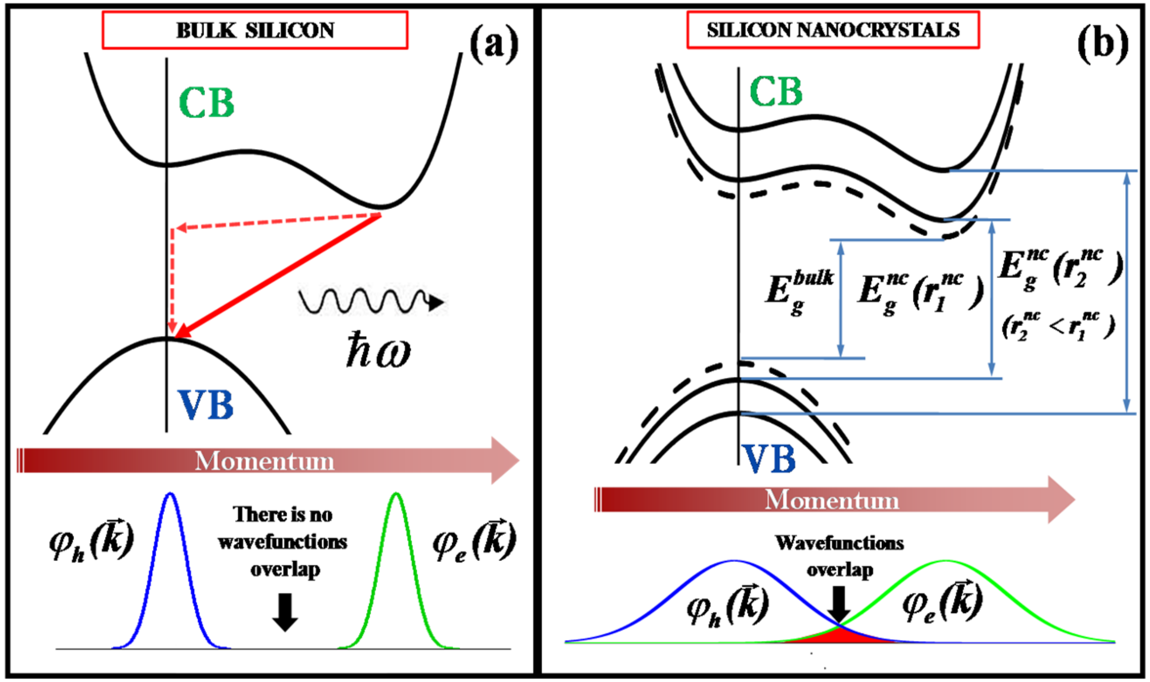
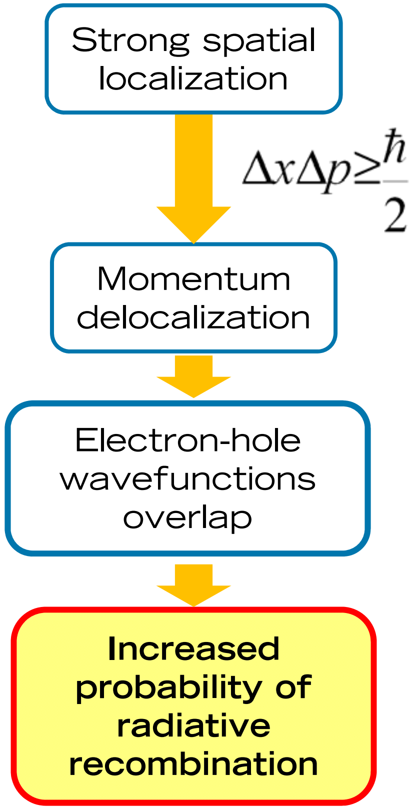
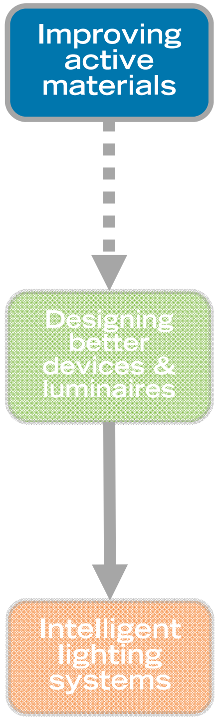
Materials for efficient and sustainable lighting

Si-nanocrystals in dielectric matrices:

- Tiny silicon nanoparticles are embedded in dielectric matrices
- The emission is based in **quantum confinement** effects:







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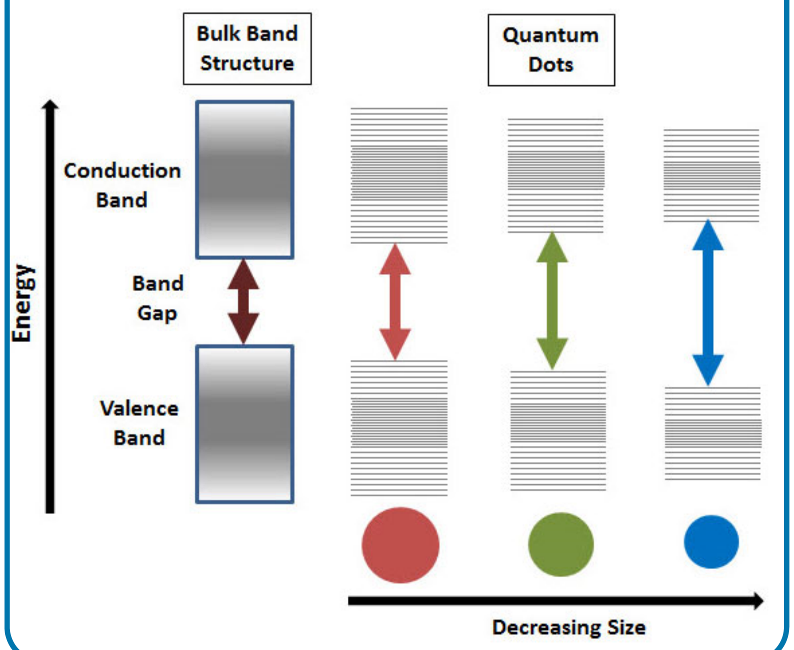
Materials for efficient and sustainable lighting

Si-nanocrystals in dielectric matrices (II):

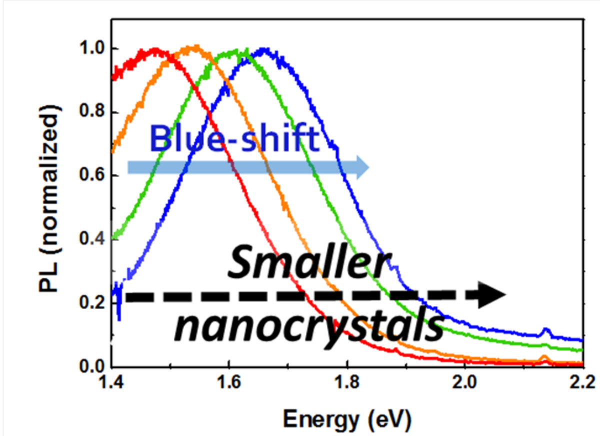
Smaller nanoparticles

induces...

Bandgap enlargement



Emission at higher energies



Tunable light emission depending on size

Improving active materials

Designing better devices & luminaires

Intelligent lighting systems

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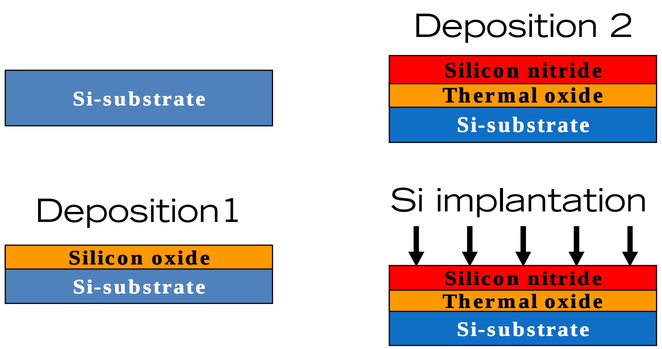
Materials for efficient and sustainable lighting

Si-nanocrystals in dielectric matrices (III):

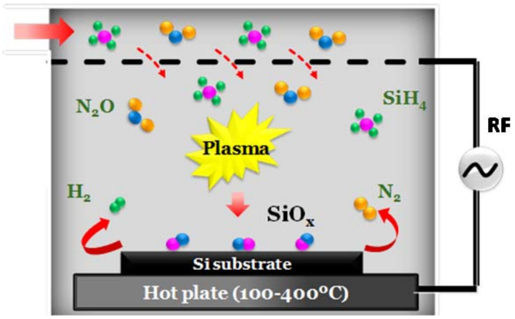
Device Fabrication: MIS devices

① Si-rich dielectrics preparation

Ion implantation



Plasma Enhanced CVD



Si-rich layers directly on a Si-substrate

② Si-nanocrystals growth: high-temperature annealing

③ Metallization

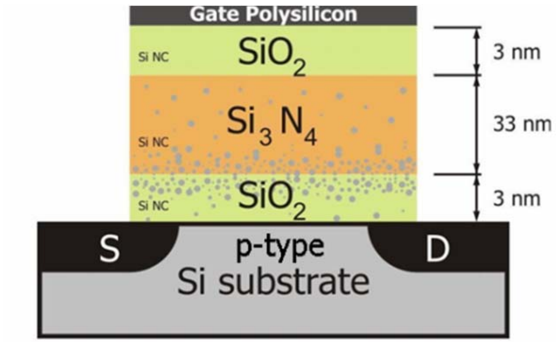
Improving active materials

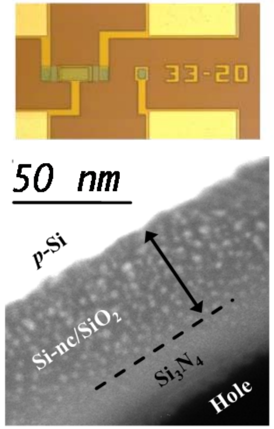
Designing better devices & luminaires

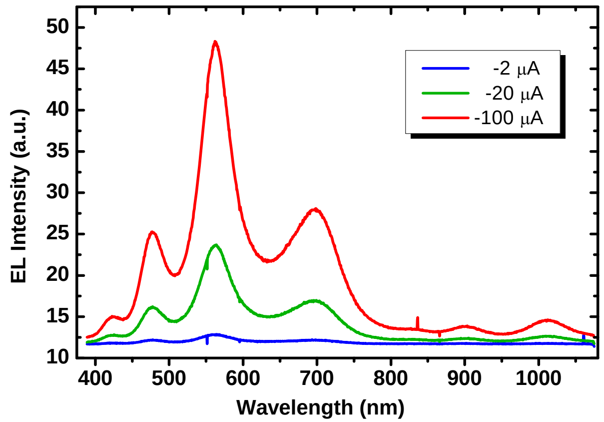
Intelligent lighting systems

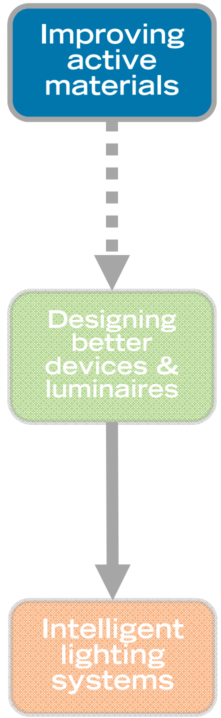
Materials for efficient and sustainable lighting

Si-nanocrystals in dielectric matrices (IV):









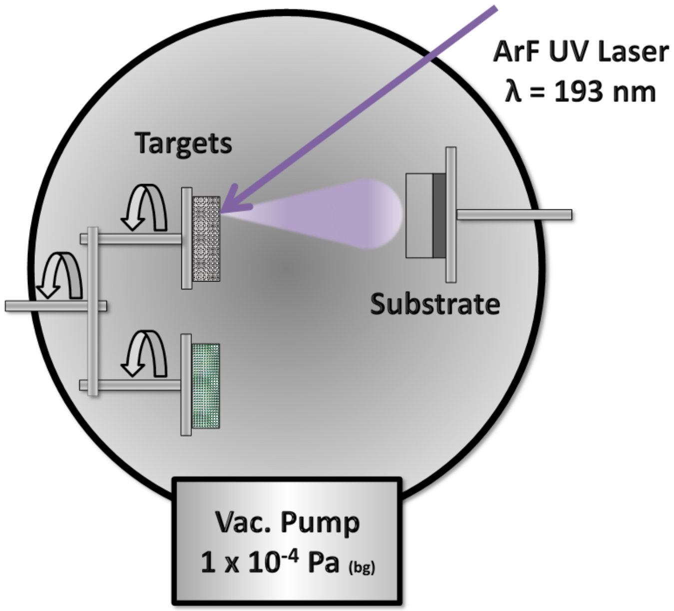
Drawbacks

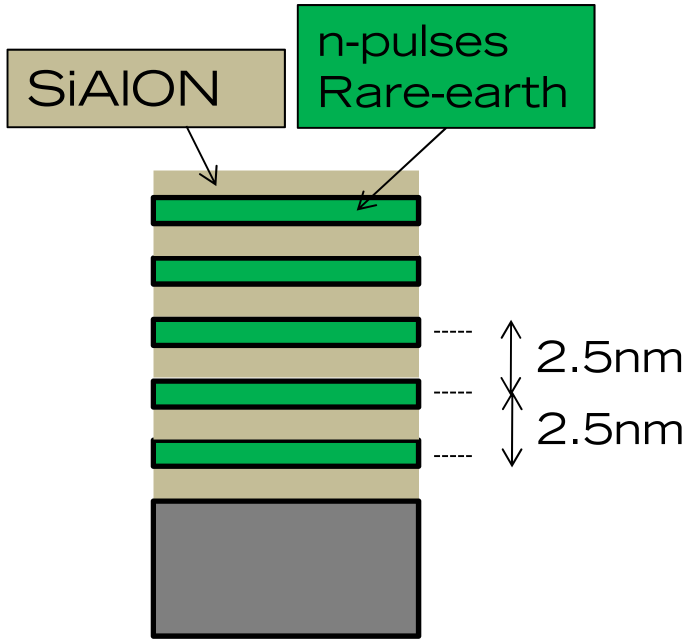
- Random Si-nanocrystals distributions avoid efficient control of device features.
- Visible but low optical power delivered
- Typically high leakage currents: poor efficiency (< 0.1%)
- Relatively high operation voltages (30 – 40 V)

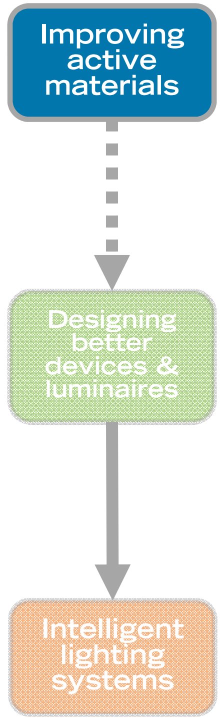
Materials for efficient and sustainable lighting

PLD matrices with rare earth ions (I)

- Rare earth ions (emitting centers) and dielectric (SiAlON) are sequentially deposited by Pulsed Laser Deposition.
- Precise control of fabrication parameters



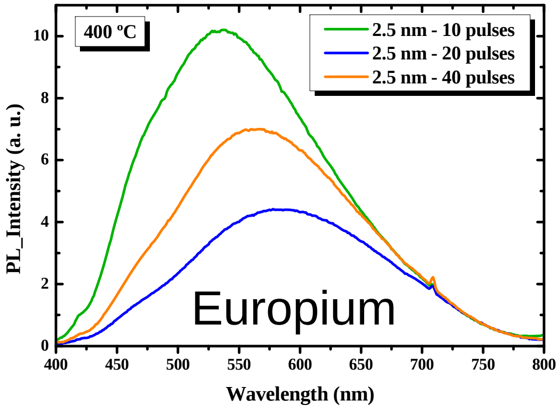




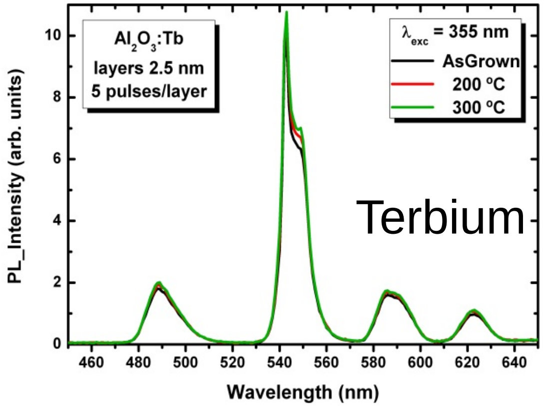
Materials for efficient and sustainable lighting

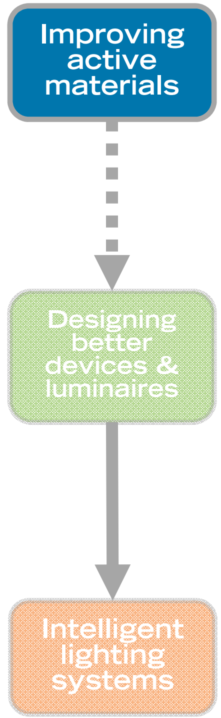
PLD matrices with rare earth ions (II):

- Only PL results available (devices fabrication in progress)



Emission in the green range





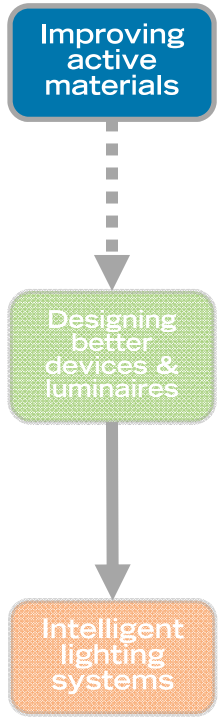
Drawbacks

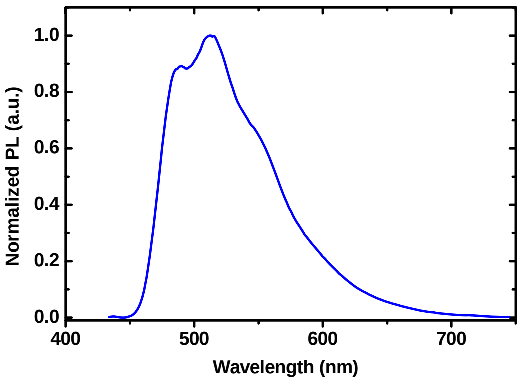
- Rare-earth are not cost-effective.
- Relatively slow deposition rates
- Observable emission under optical pumping but still to be improved.

Materials for efficient and cost-effective lighting

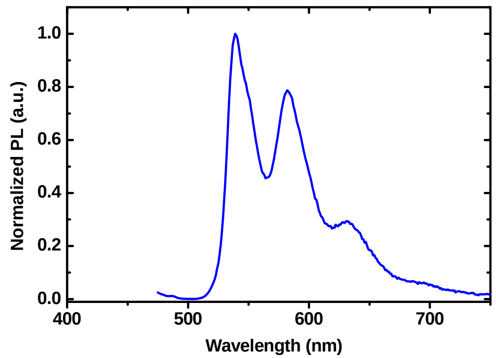
Organic phosphor for wavelength tuning (I)

- Conventional blue LEDs emission is **downconverted** by means of **metalorganic phosphors** are used to convert
- Platinum atoms acts as emitting centers
- The emission wavelength can be tune by changing the functional groups around the Pt atoms.
- Conversion efficiencies up to **85 %** achieved.



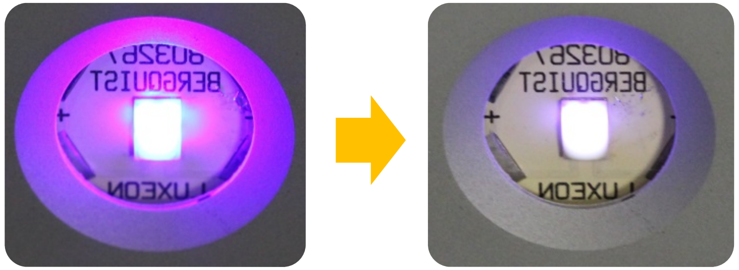


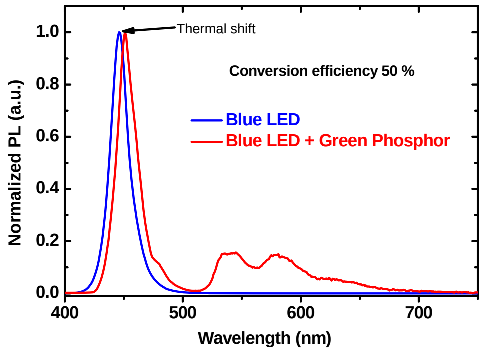
Examples of Greenish emission



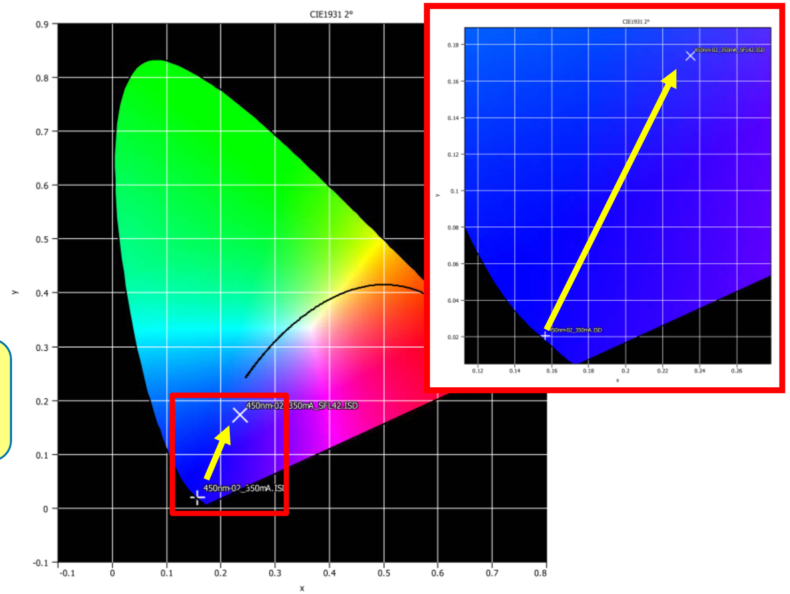
Materials for efficient and cost-effective lighting

Organic phosphor for wavelength tuning (II)





Color change



Improving active materials

Designing better devices & luminaires

Intelligent lighting systems

Drawbacks

- Phosphor conversion efficiency to be improved.
- Reliability? To be confirmed

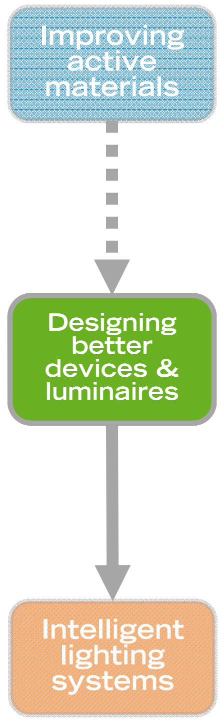
Design and optimization of devices and luminaires

At device and luminaires level the actions focus on:

Improving the design of devices and luminaires

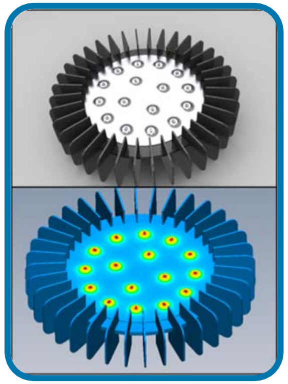
<u>In order to</u>:

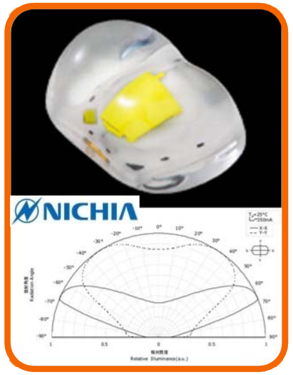
- Improve thermal management: extended lifetime and minimum peak shift
- Increasing the optical performance: maximum output power and color mixing
- Minimizing production cost



Design and optimization of devices and luminaires

3D CAD design





3D design of devices and luminaires

Focus on:

- **Improving thermal management**
  - Translates into: **Increased reliability; Longer device lifetime**
- **Increasing light extraction; Beam shaping**
  - Translates into: **Larger output power; Better efficacy (lm/w)**

Improving active materials

Designing better devices & luminaires

Intelligent lighting systems

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Design and optimization of devices and luminaires

CFD simulations of thermal management

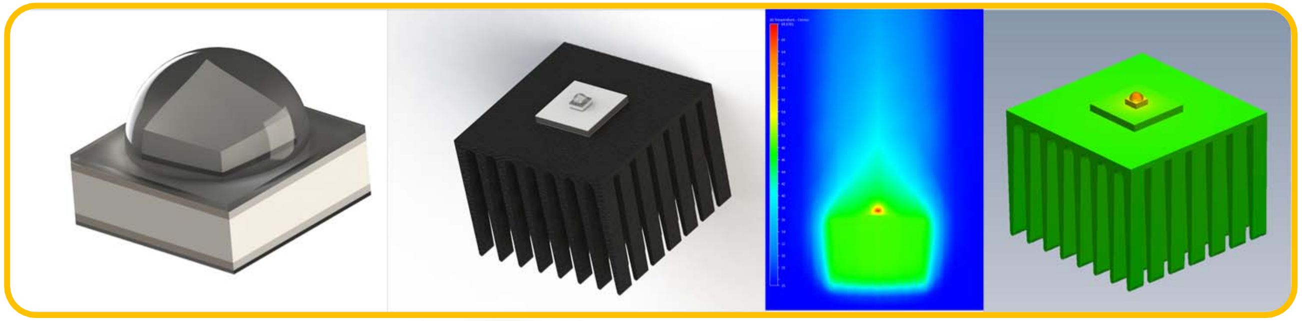
Appropriate heat dissipation

requires

- Accurate design of LEDs and luminaires
- Right choice of materials (heat sink, TIM, encapsulants ...)
- Right dimensioning of heat sink

minimizes

- Device degradation
- Color shift
- Output power reduction



Improving active materials

Designing better devices & luminaires

Intelligent lighting systems

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Design and optimization of devices and luminaires

Raytracing simulations of optical performance

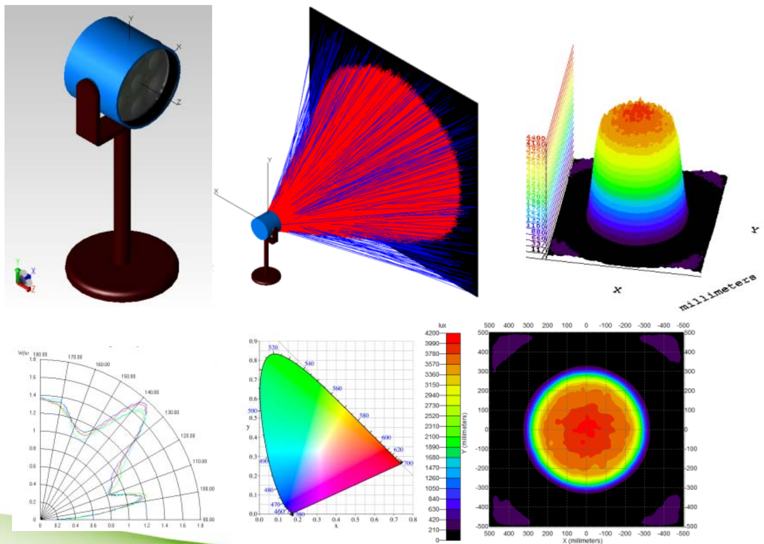
Optimum optical design

requires →

- Adapting optical elements to illumination conditions
- Right choice of materials (frosted, faceted, ...)

assures ↓

- Maximum output power
- Color mixing (RGB, multi chip devices,...)
- Adequate beam shape



Improving active materials

↓

Designing better devices & luminaires

↓

Intelligent lighting systems

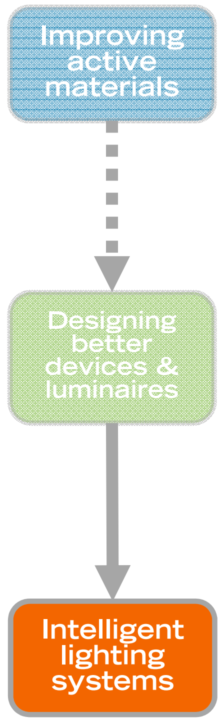
Intelligent lighting systems

At system level the actions stress on:

Implementing smartlighting systems

In order to:

- Reduce power consumption: dimming, occupancy sensors, daylight sensors...
- Enhance illumination quality
- Incorporate smart applications: VLC, tracking people...

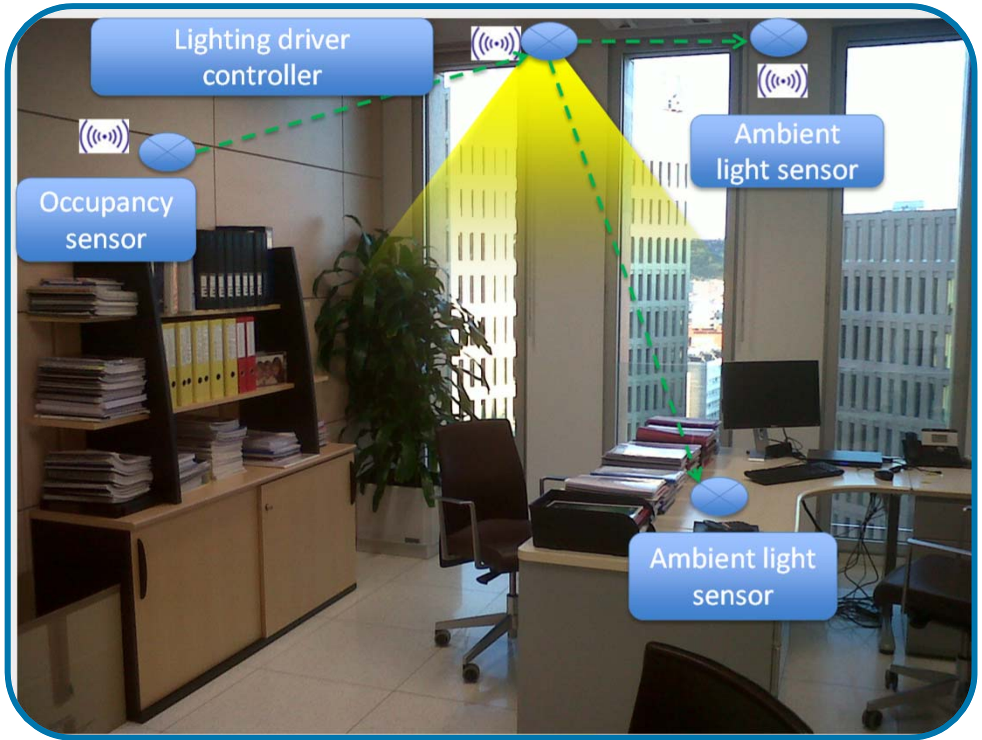


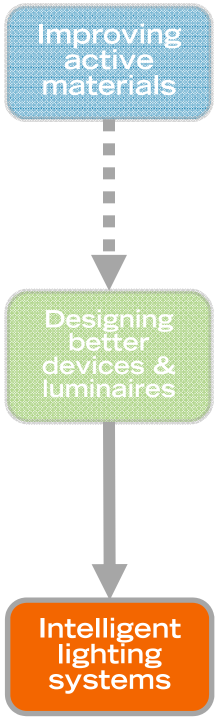
Intelligent lighting systems

Control strategies

The implementation of intelligent lighting systems can save up to 30 % of energy in conventional CFL

In LEDs systems this saving can be up to 40-45 %





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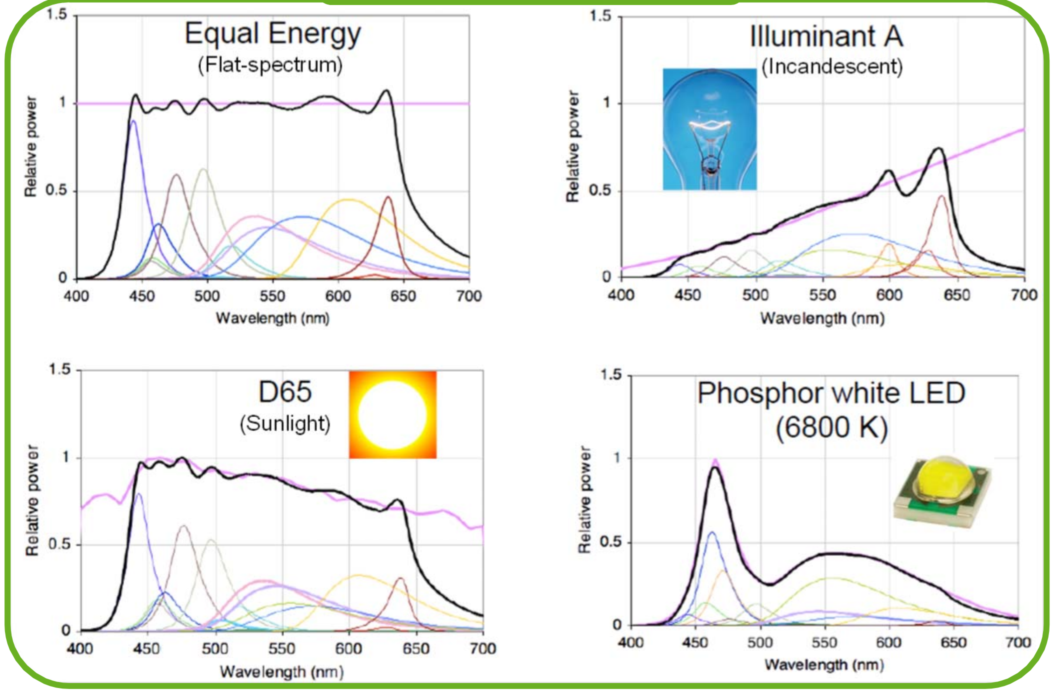
Intelligent lighting systems

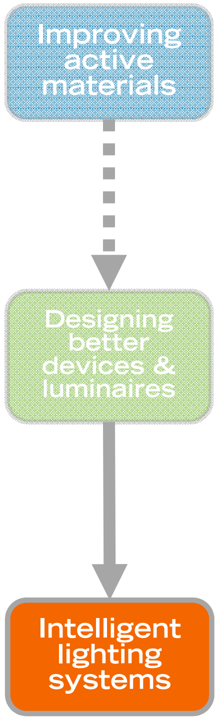
Spectral reproduction

LED arrays of different colors to reproduce any spectrum of light: HIGH QUALITY ILLUMINATION

Standard sources



Spectrum adapted to applications



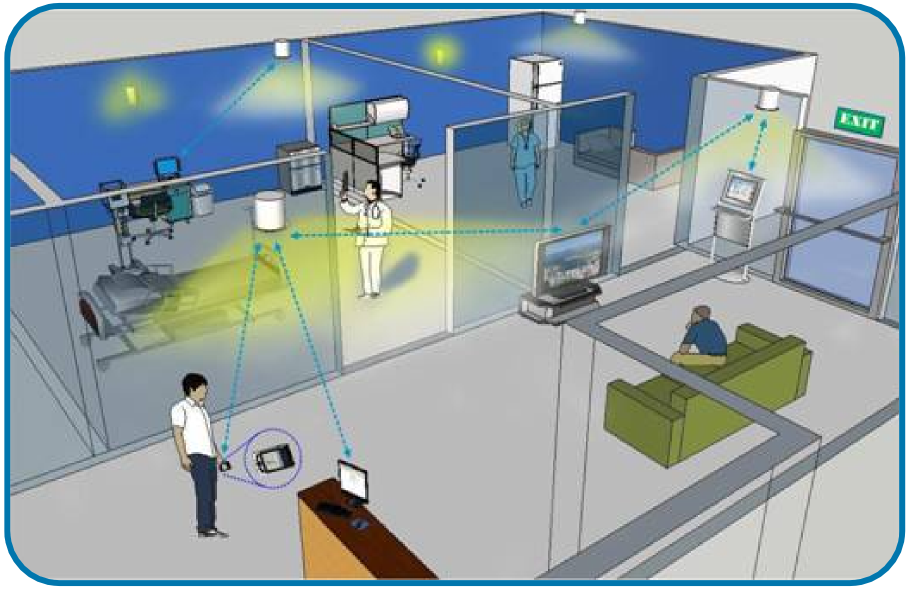
Intelligent lighting systems

VLC (Visual light communications) (I)

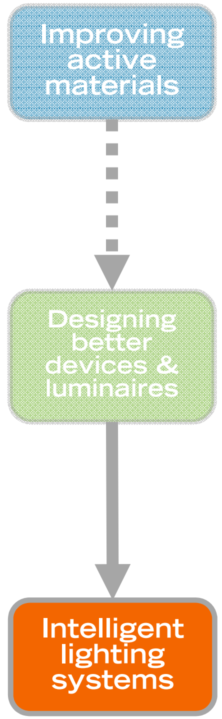
Data transfer using light signal from conventional LED fixtures

The fast modulation required has **no effect on human comfort**.

Energy saving: takes advantage of already installed systems



- Mobile connectivity
- Internet
- Location services: people, cars or objects
- Uses in restricted areas: Aviation, hospitals, etc.
- Underwater communications

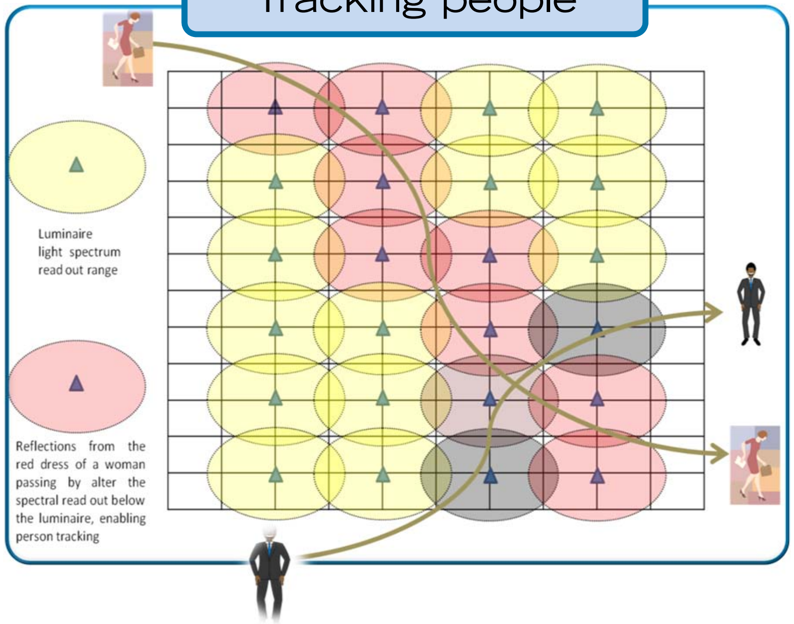


Intelligent lighting systems

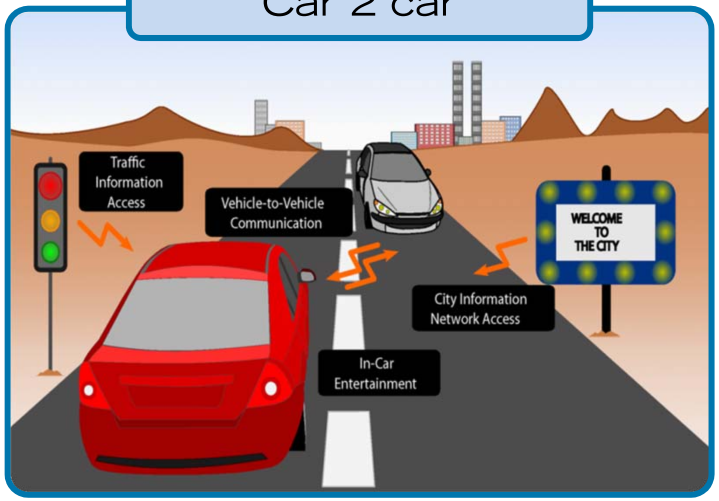
VLC (Visual light communications) (II)

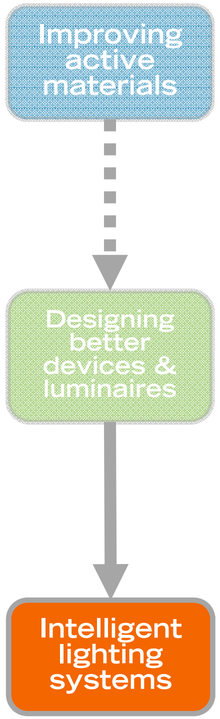
Examples

Tracking people



Car 2 car





http://www.youtube.com/watch?v=YPCAtCJGaU0

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Head of the Group

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Senior Researcher

Dr. Jorge E. Higuera
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Oscar Motto
MSC Researcher

Wim Hertog
PhD Student

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GOBIERNO DE ESPAÑA
MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD

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THANKS !

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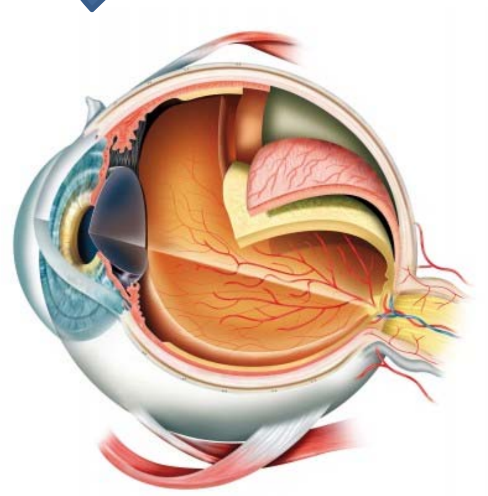
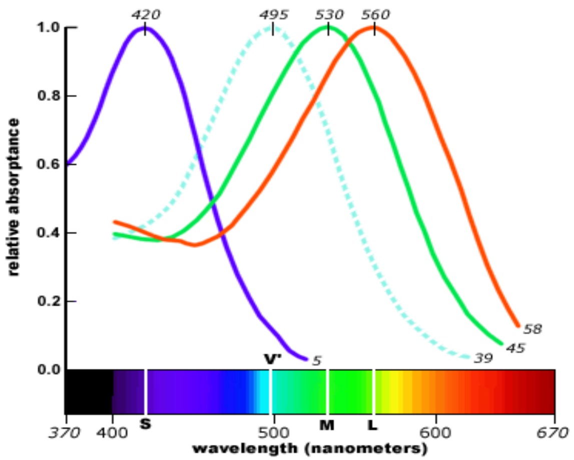
What Is Light?





- Lens -> Retina
  - Cones: bright – color
  - Rods: dim - mono
- Brain: Image Processing
- 4 eye sensitivity curves
  - L (450nm)
  - M (530nm)
  - S (560nm)

  -> Cones
  - Rods (498nm)

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