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Deep UV-LEDs based on group III-nitride for water disinfection applications

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Deep UV-LEDs based on nitrides for water disinfection

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OUTLINE:

UV disinfection concept

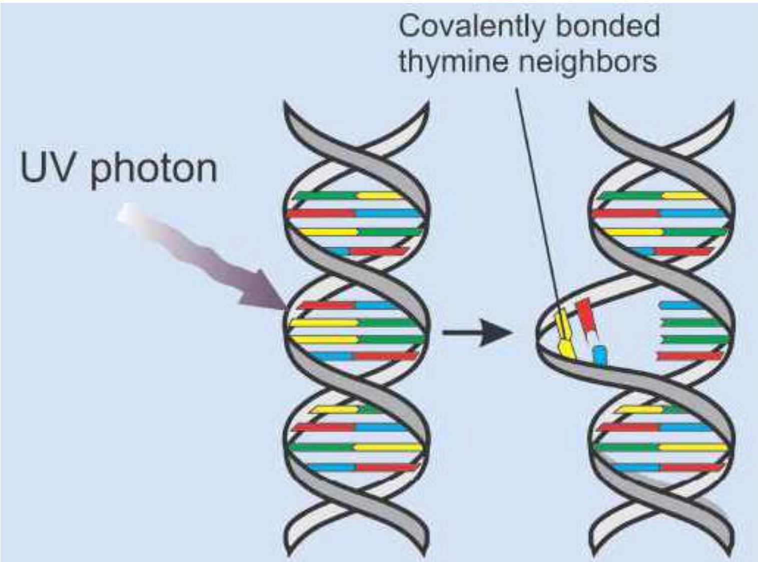
UV light sources

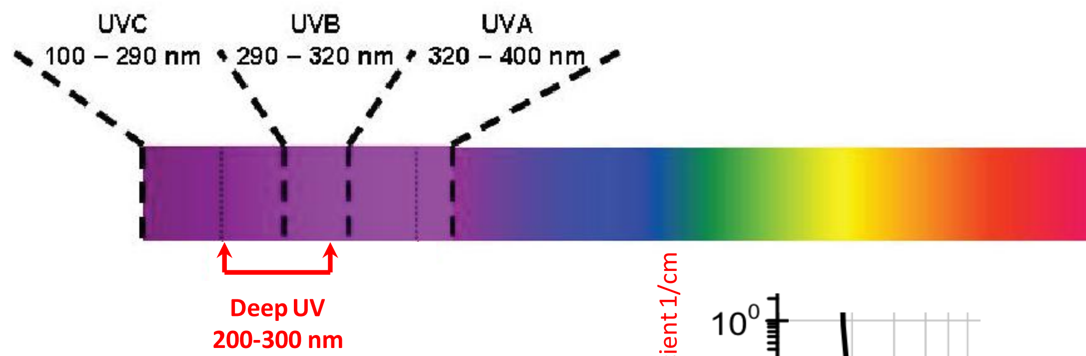
State of the art in nitride based UV-LEDs

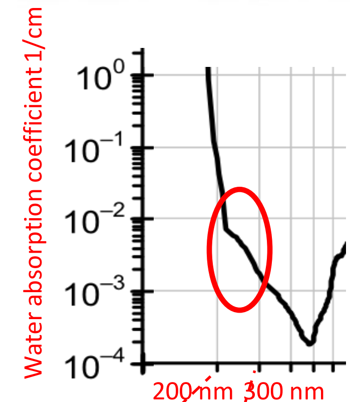
UV-LEDs: Material and device issues

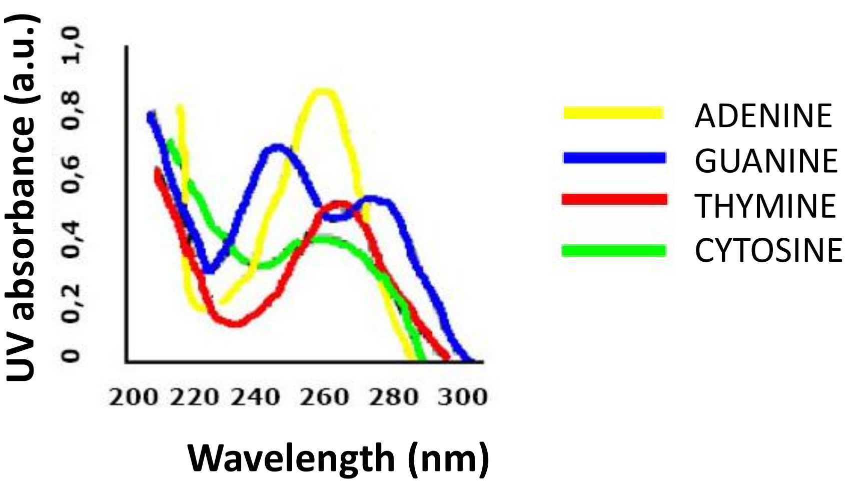
Discussion

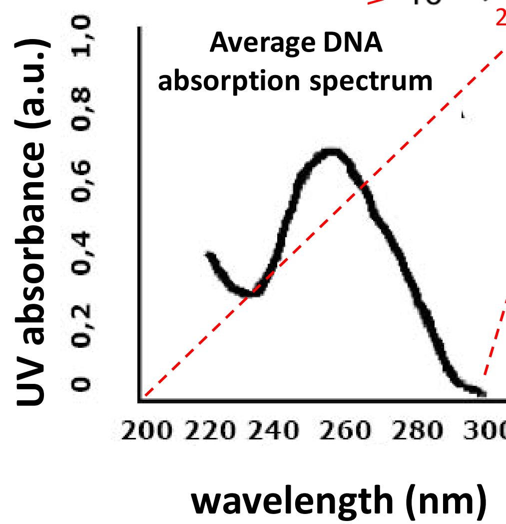
UV disinfection











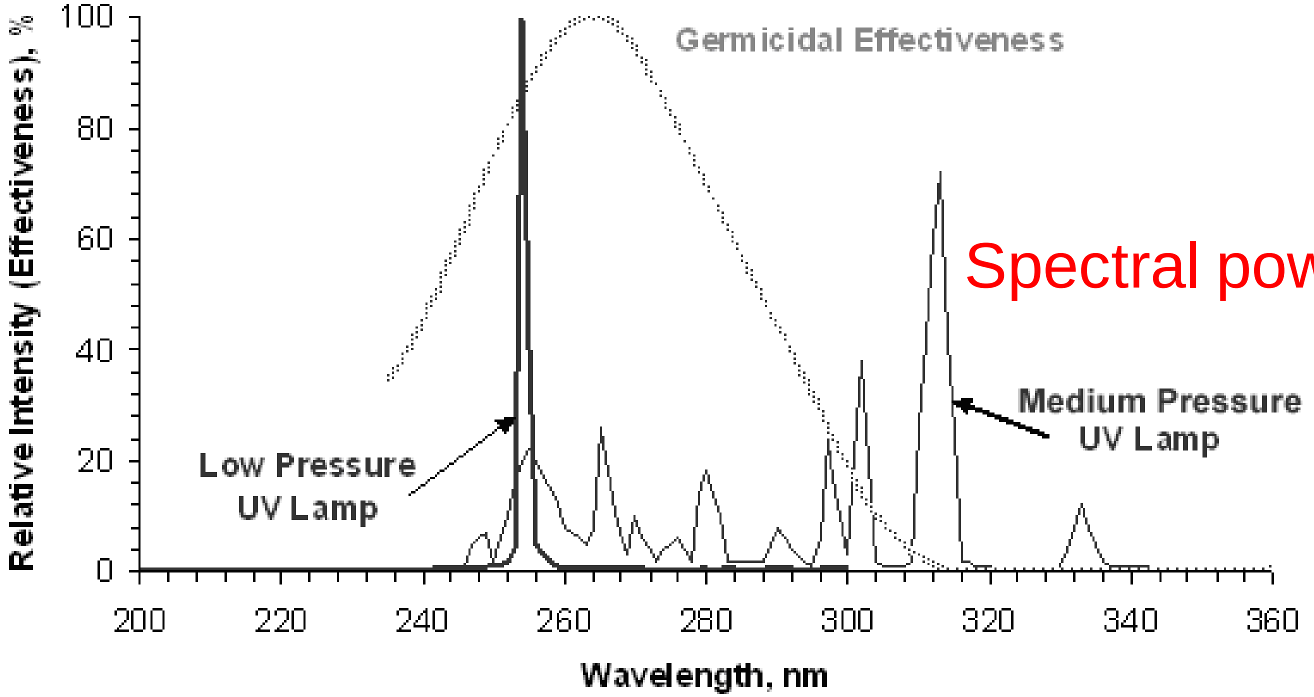
Actual UV system

LP (LPHO) Hg-lamps

narrow emission peak, λ=254 nm
operating power = 15-200 W
operating temperature = 40°C
conversion = 30-35 %
Ideal for small treatment volume

MP Hg-lamps

wide emission, λ=190÷350 nm
operating power = 0.4-7 kW
operating temperature = 600-900°C
conversion = 15 %
treatment volume = 600 m^3/h

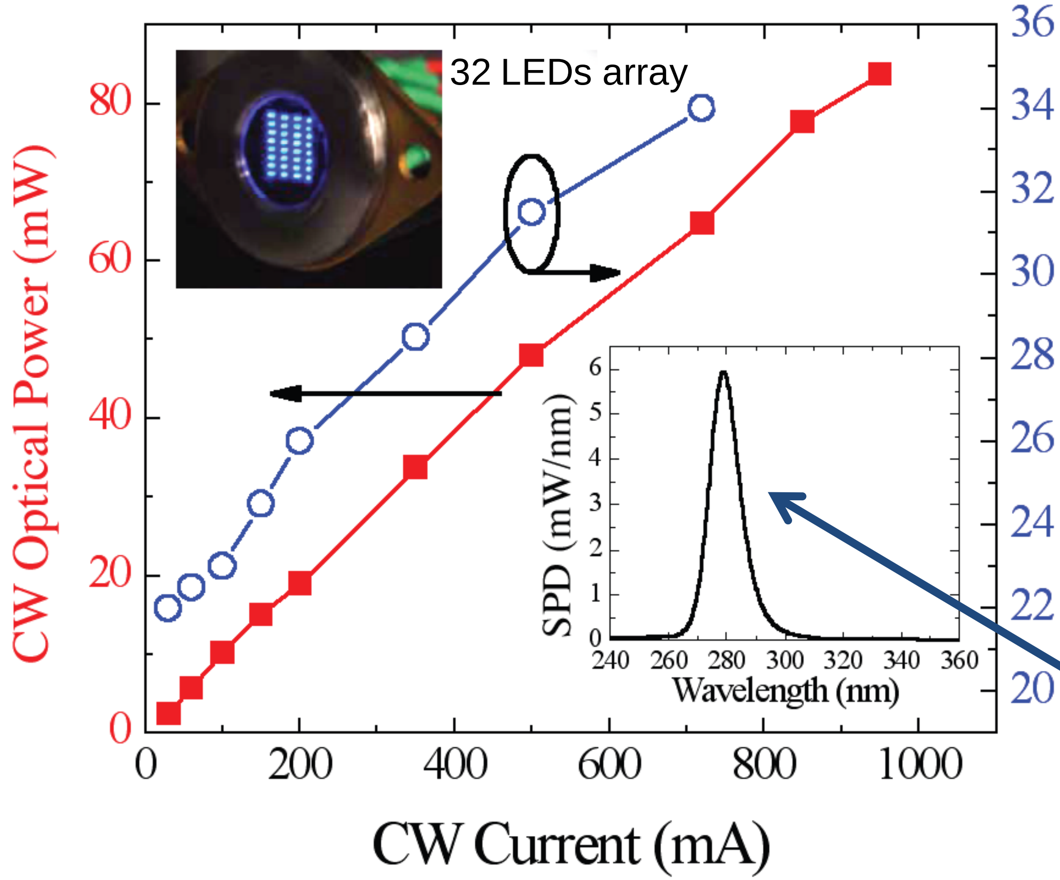


Spectral power distribution

What is a LED ?

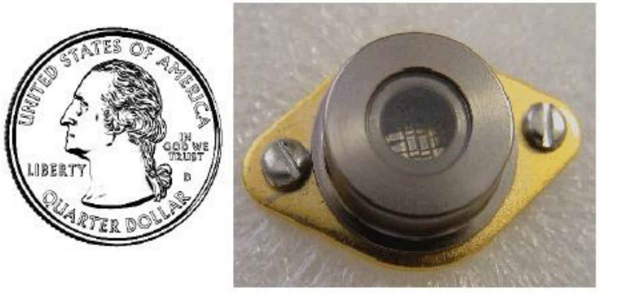
Light Emitting Diode

Solid-state light source which converts input electrical energy into output optical radiation at the desidered wavelenght, depending on the semiconductor material



~15 nm FWHM

Multiple chip LED lamp



5-9 mm chip diameter

deep UV-LEDs vs Hg-Lamps

Robustness

Compact light source

Environmentally safe

Faster start-up time

Longer lifetime (26,000 h)

Low power consuming

Low cost

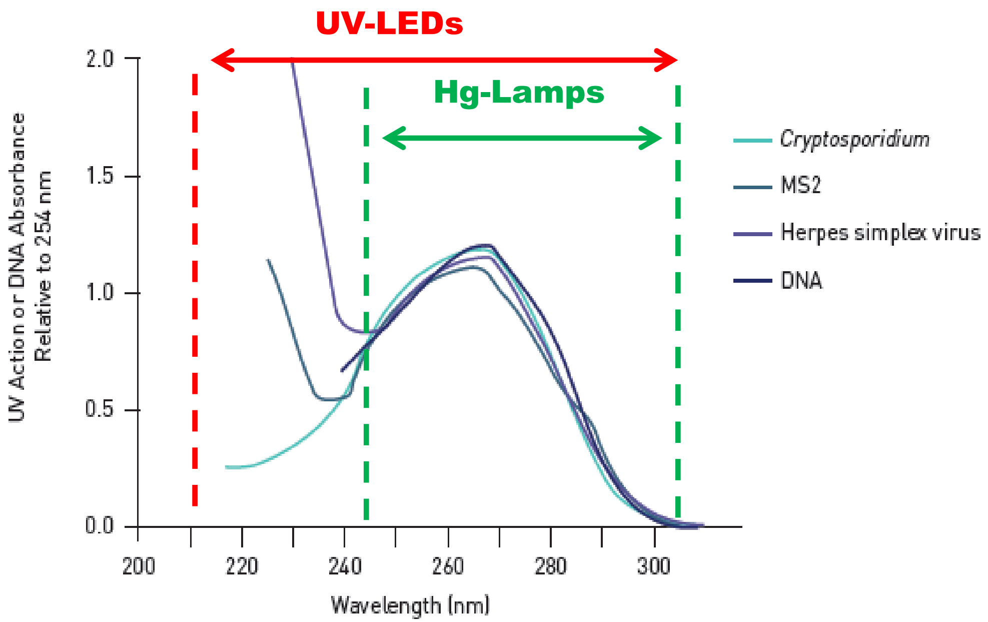
Emission wavelength tunability

Highly toxic (disposal problems)

Fragile **Bulky**

Limited lifetime (4,000-12,000 h)

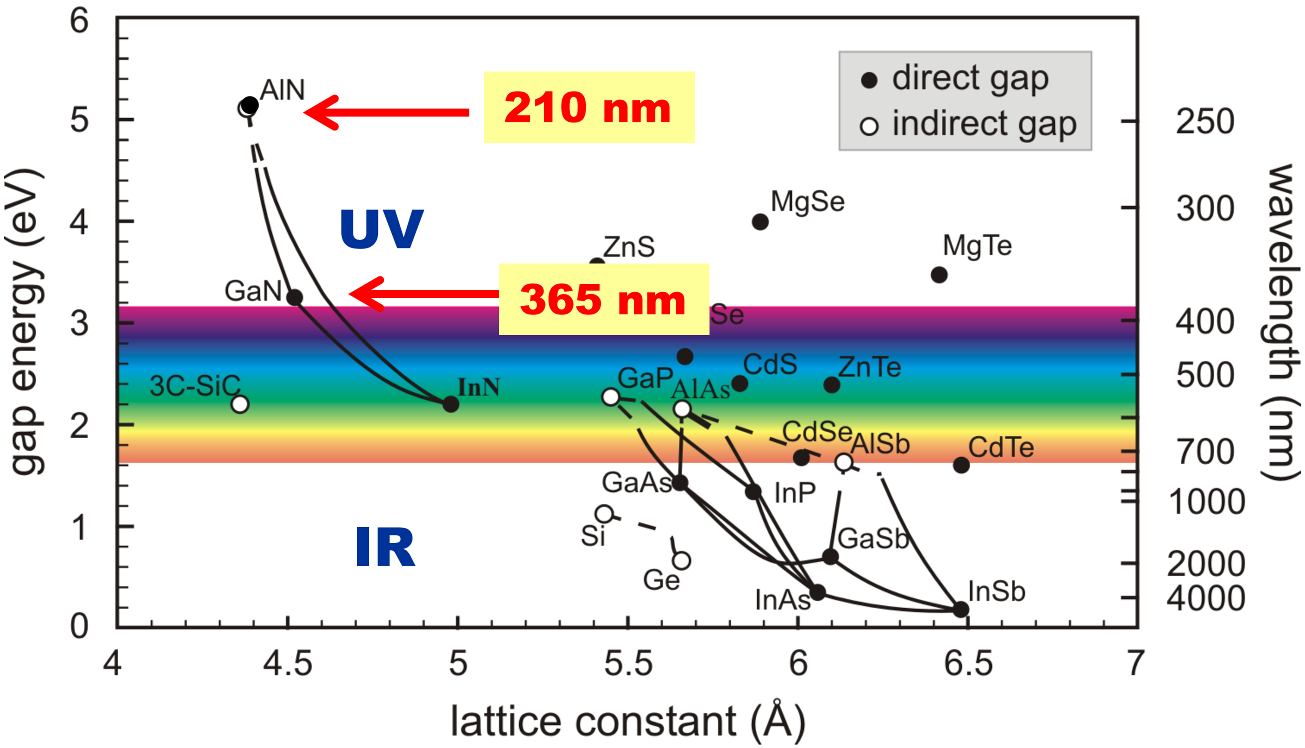
High power consuming

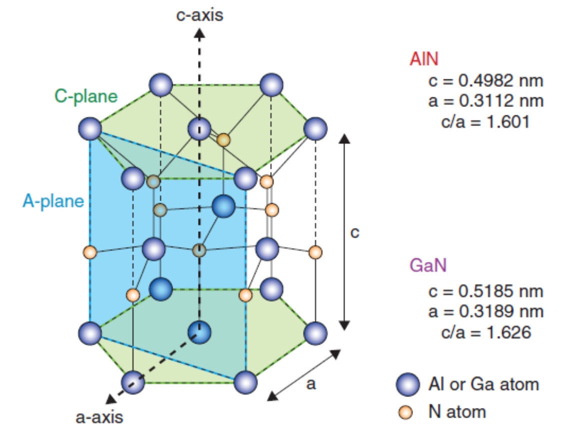


Selectivity

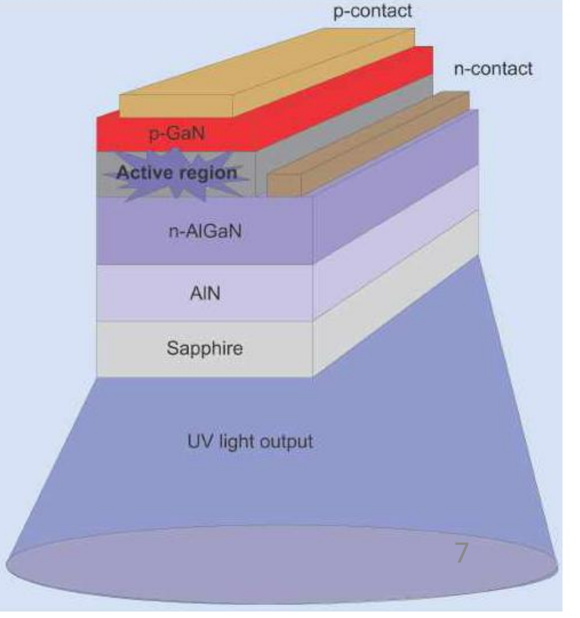
Ideal material system

$Al_xGa_{1-x}N$ based UV-LEDs





Wurtzite

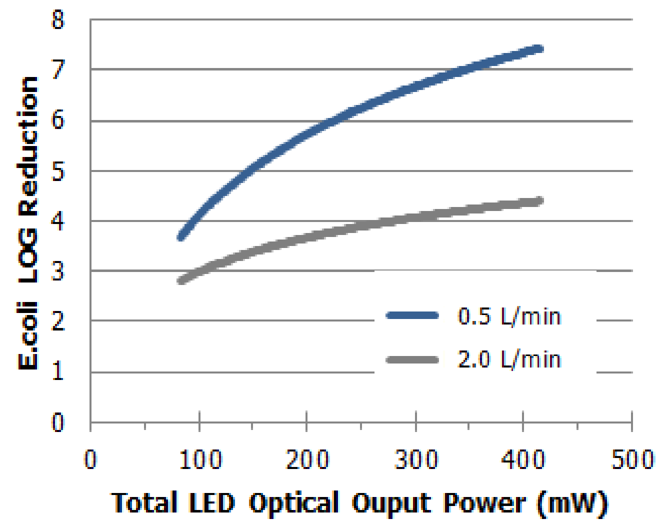


UV-LEDs: disinfection performances

4 multi-chip LED lamps
200 mW

λ=275-285nm
chip 1.5mm x 1.5mm
active area 1 mm^2

SET i



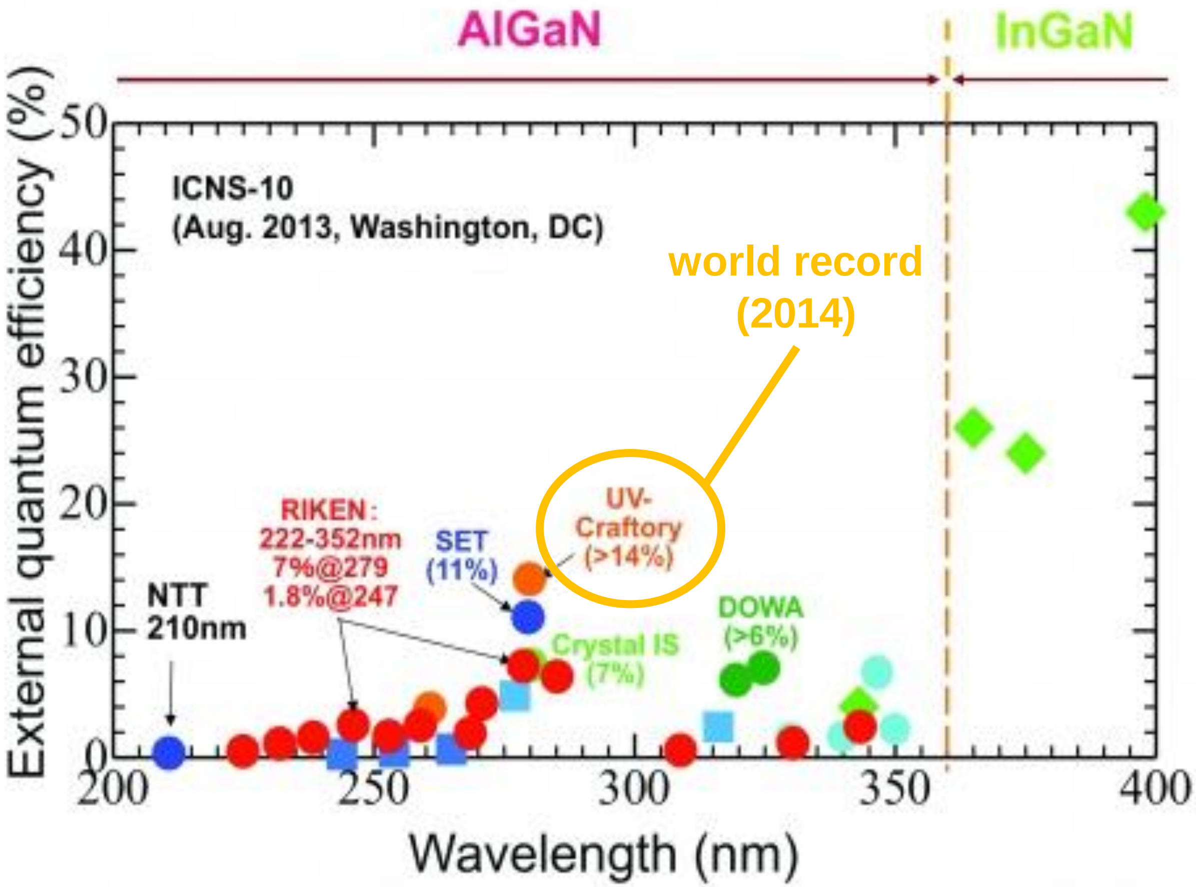
NSF testing procedures

First commercial prototype (May 2012)

λ=275nm

Aquionics and
Dot Metrics Technologies

State of the art for UV nitride LEDs

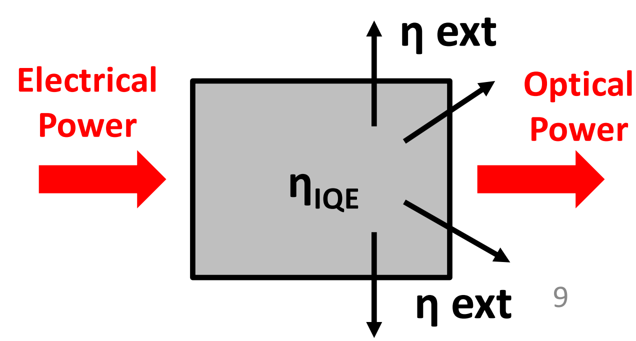


$$WPE = \frac{output\_optical\_power}{input\_electrical\_power} = \eta_{EQE} \frac{\hbar\omega}{eV}$$

Material quality

Device

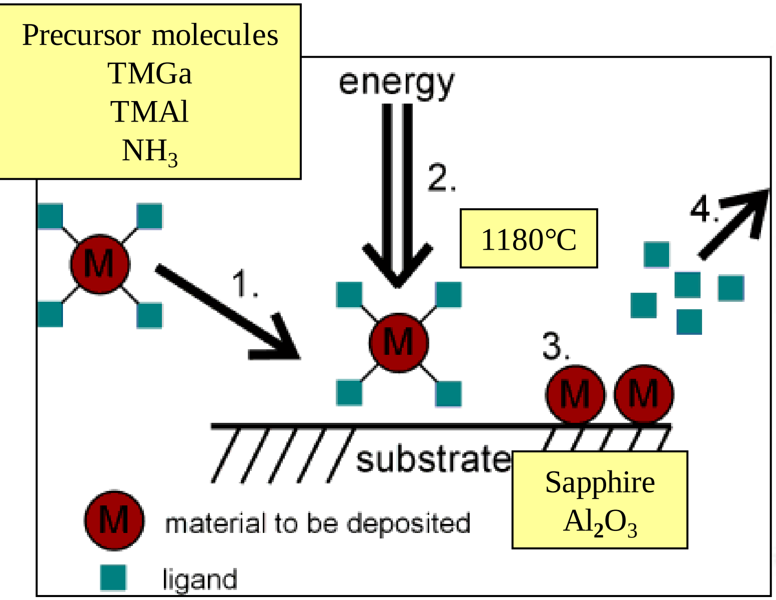
$$\eta_{EQE} = \eta_{inj} \times \eta_{rad} \times \eta_{ext}$$



$Al_xGa_{1-x}N$/GaN epitaxial growth process

MOCVD (Metal Organic Chemical Vapour Deposition)

Epitaxy=highly ordered growth



Material Issues

Lack of a suitable substrate (high lattice and thermal mismatch)

Low Al species surface mobility (3-D island growth)

Quantum confined stark effect

↓ η_{rad}

UV absorption of p-GaN contact layer ↓ η_{ext}

$Al_xGa_{1-x}N$/GaN growth process at NNL-CNR group

High Temperature AlN buffer layer on sapphire substrate

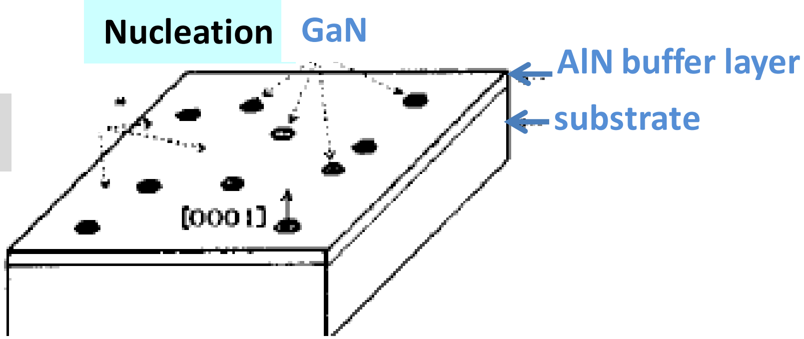
- Reduce interfacial energy
- Increase nucleation density
- Enhance lateral growth

High quality continuos films

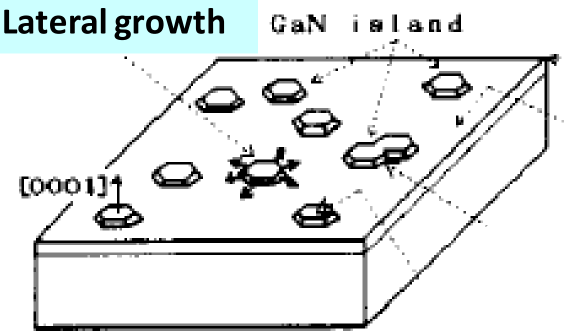
Flat growth

Low defect density ~$10^7 cm^{-2}$

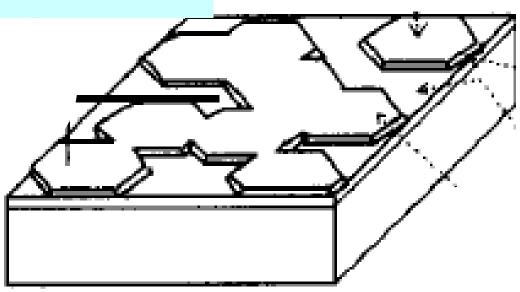
1 Nucleation



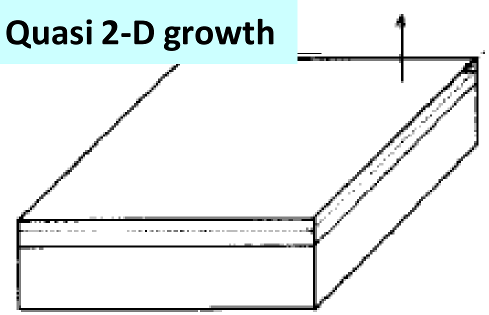
2 Lateral growth



3 Coalescence

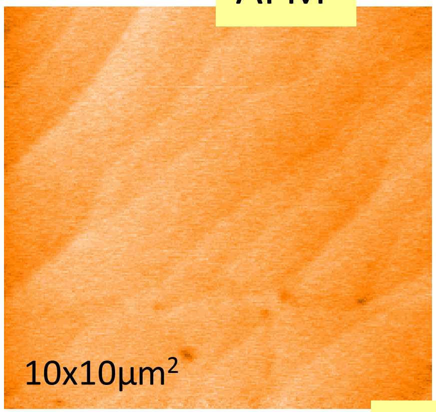


4 Quasi 2-D growth

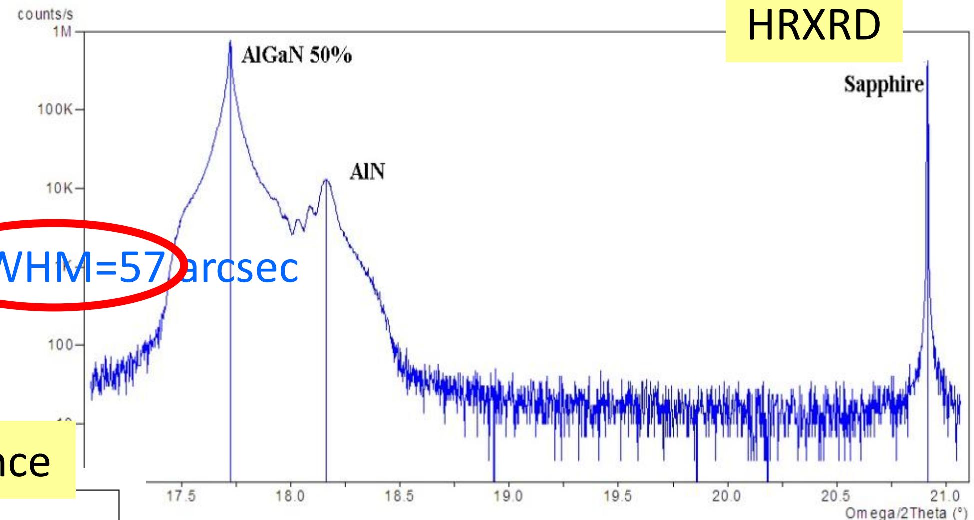


Material: structural and optical properties

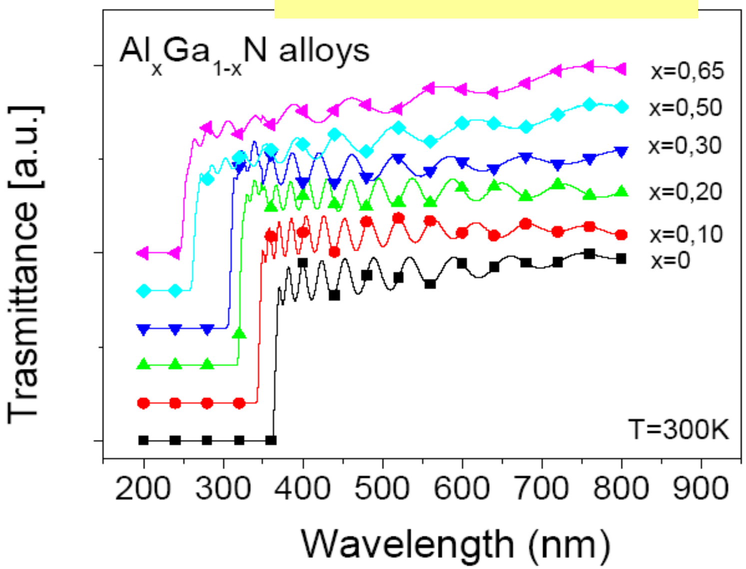
AFM



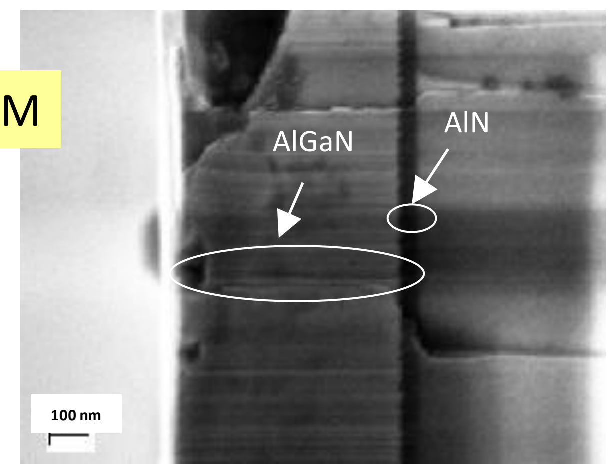
HRXRD



UV-vis trasmittance



SEM



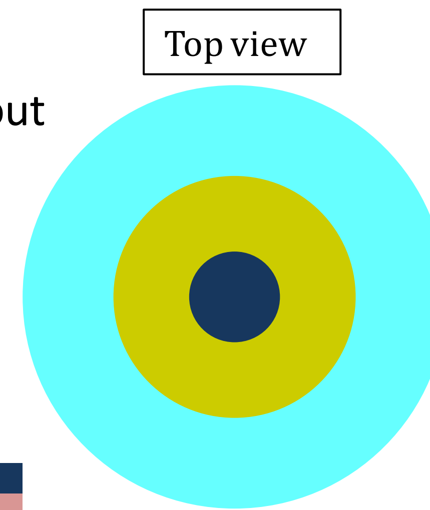
- Linewidth of X-Ray Rocking curve ~**60arcsec**
- Density of threading dislocations **~10^7cm^{-2}**
- Root mean square surface roughness: **0.6nm** over 10x10µm²

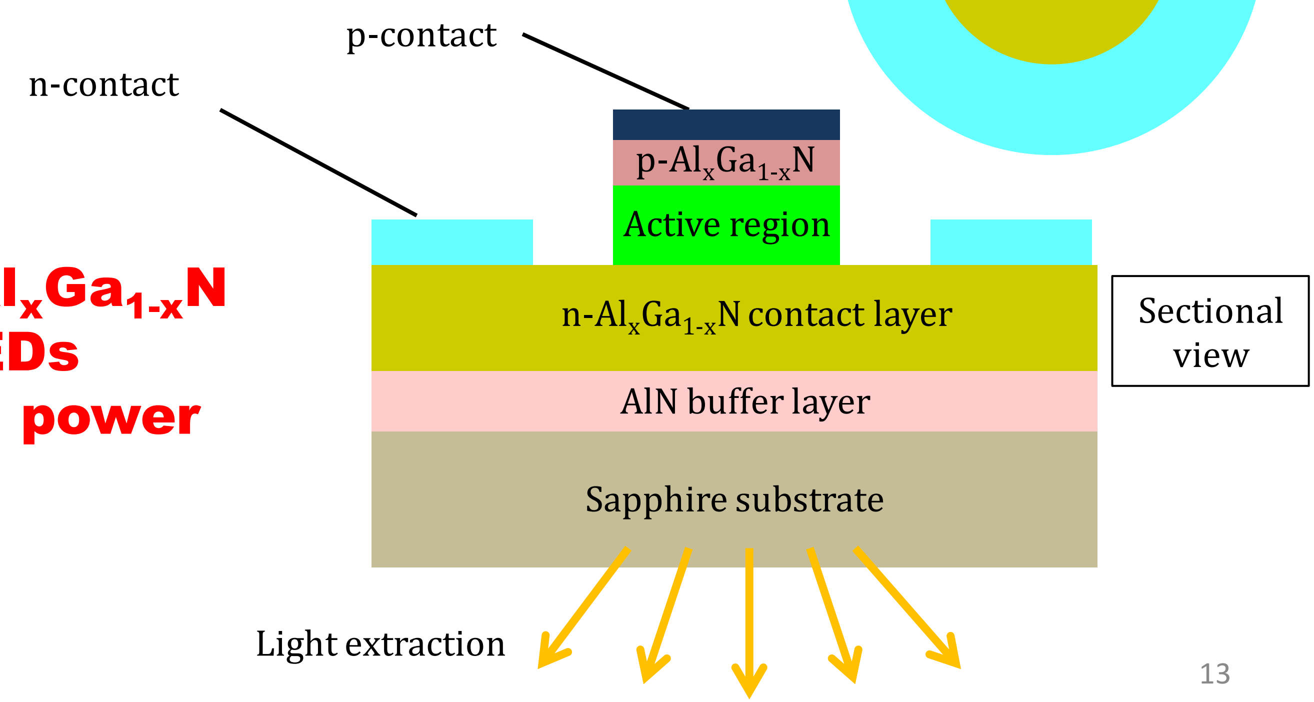
J. Appl. Phys. **105, 063510 2009**

Planned strategy

Design of an ideal architecture → Quantum confinement heterostructures; Device layout

Refinement of microfabrication process
(transparent p-contact based on graphene, optimization of carrier injection)





Development of Al$_x$Ga$_{1-x}$N based UV-LEDs with high optical power

CONCLUSIONS

- UV-LED device represents an attractive substitute to the commercial UV light sources for water disinfection applications because of its emission wavelengths tunability, compact form, non-toxicity, long lifetime and low power consumption.

- Bench-scale tests have demonstrated the effectiveness of UV-LEDs on different microorganisms using low flow rate but higher optical powers are required for wide scale implementation.

- By improving device design and material quality should be possible to achieve adequate value of EQE and to customize it for appropriate microbial target.

- Nitride based UV-LEDs have advanced from less than 0.1% EQE to 14% over the past ten years and further improvements are expected in the future as occurred for visible LEDs.