Innovative relaxed InGaN engineered substrates for RGB Micro-LEDs

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Efficient red microLEDs need for AR/VR micro-displays

- Efficient blue and green LEDs are in Nitride, red LEDs are in Phosphide
- Phosphide red LEDs are intrinsically not efficient at micrometer-scale (≤ 10 µm)
- Nitride red microLEDs are the ideal solution
- <u>but</u> efficiency is limited by strain between substrate and the InGaN structure
- → need relaxed InGaN engineered substrate for strain management

Agenda

- 1- InGaNOS: the relaxed InGaN engineered substrate
- 2- First red microLEDs
- 3- Conclusion and perspectives

PART 1

InGaNOS: the relaxed InGaN engineered substrate

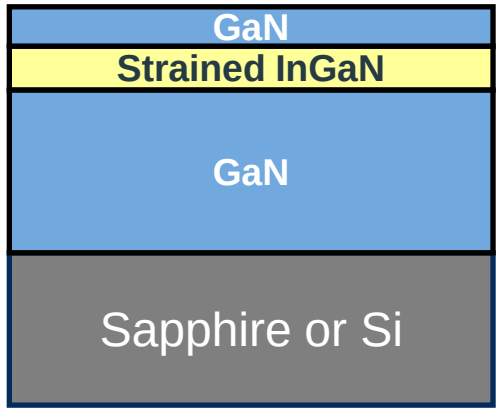
Nitride red LEDs non availability is caused by thermodynamic & strain limitations

- Soitec targets to reduce strain between InGaN (Active Layer) and GaN

Current technology
Strain between Active Layer & GaN

InGaN Active Layer

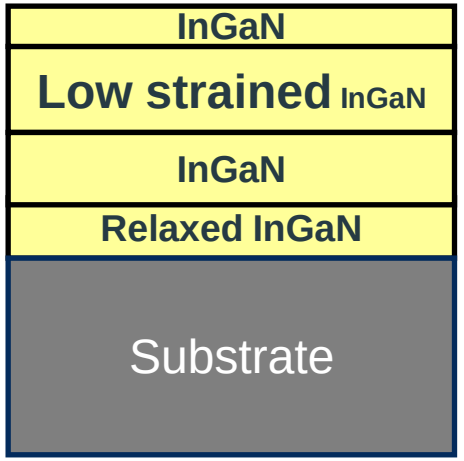
GaN on substrate



Ideal low strain structure:
Full InGaN structure

InGaN Active Layer

Relaxed InGaN on substrate



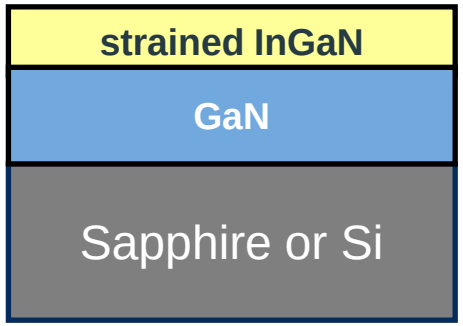
- How to fabricate full InGaN structure ?

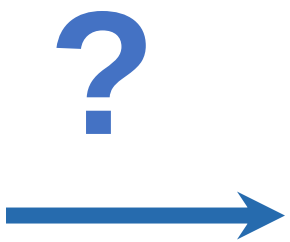
Fabrication of relaxed InGaN layer

- Starting material: strained InGaN Template

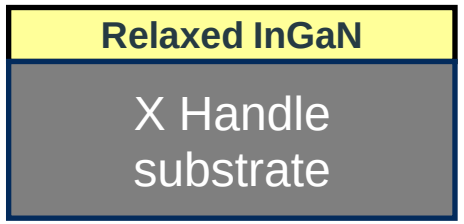
- Targeted substrate: relaxed InGaN layer on handle substrate

Starting material:
Strained InGaN Template





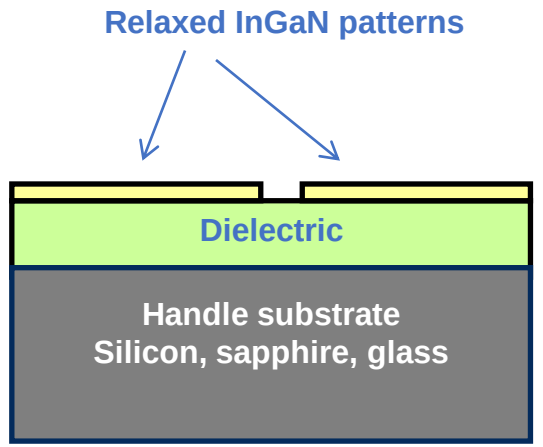
Target:
relaxed InGaN layer on handle substrate



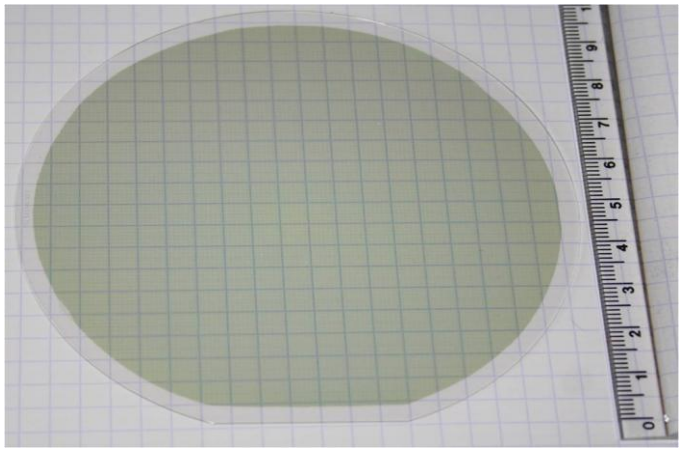
- How to fabricate substrate with relaxed InGaN layer?

Soitec has developped relaxed InGaN substrates

- Top relaxed InGaN layer
  - Ga-face epi-ready substrate
  - Monocrystalline InGaN layer, C plane orientation
  - Pattern size: from 1x1 mm² down to 5x5 µm²
  - Lattice parameter: from 3,200 to 3,214 Å
- Dielectric layer compatible with GaN growth
- Handle substrate agnostic (Sapphire, Silicon, glass)
- Development and microLED growths are done
- on InGaN-on-Sapphire (InGaNOS)

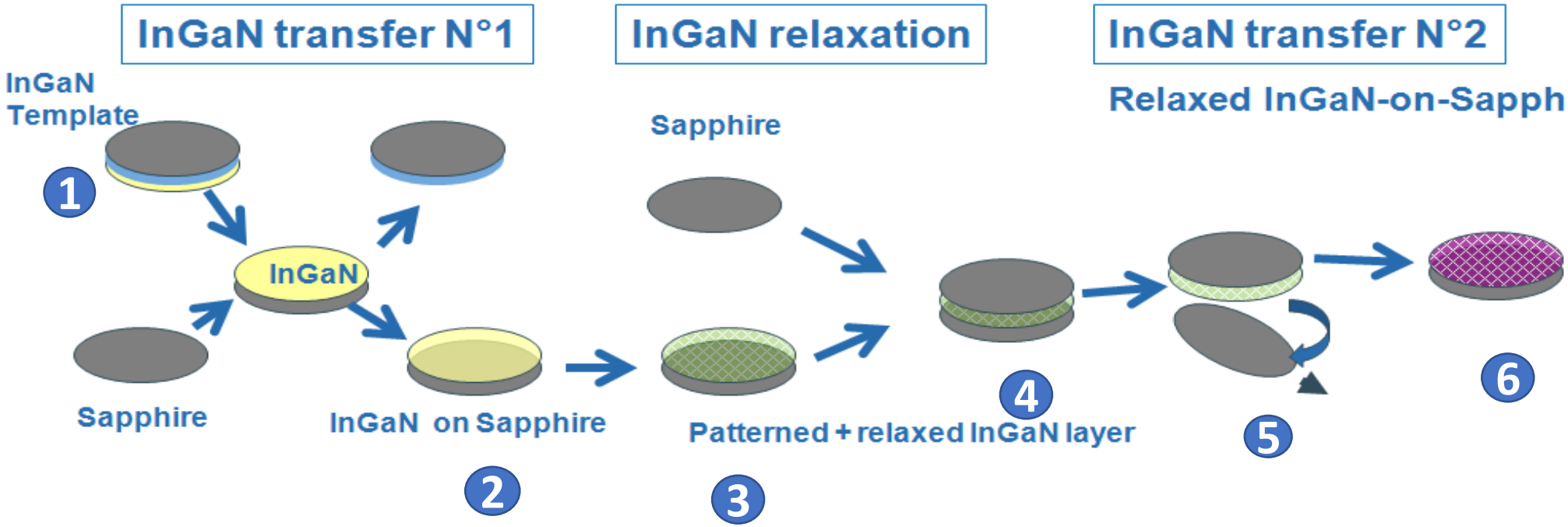


Structure of InGaN-on-X



100mm InGaN-on-sapphire

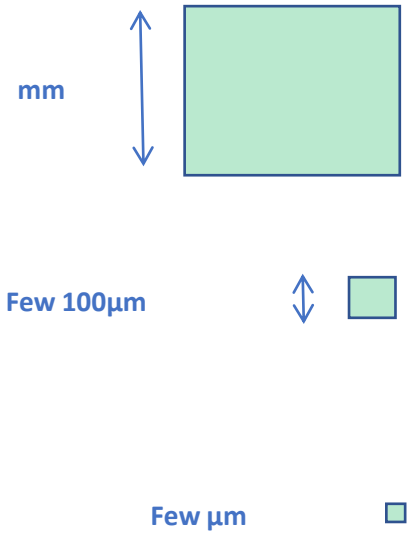
InGaNOS substrate fabrication process

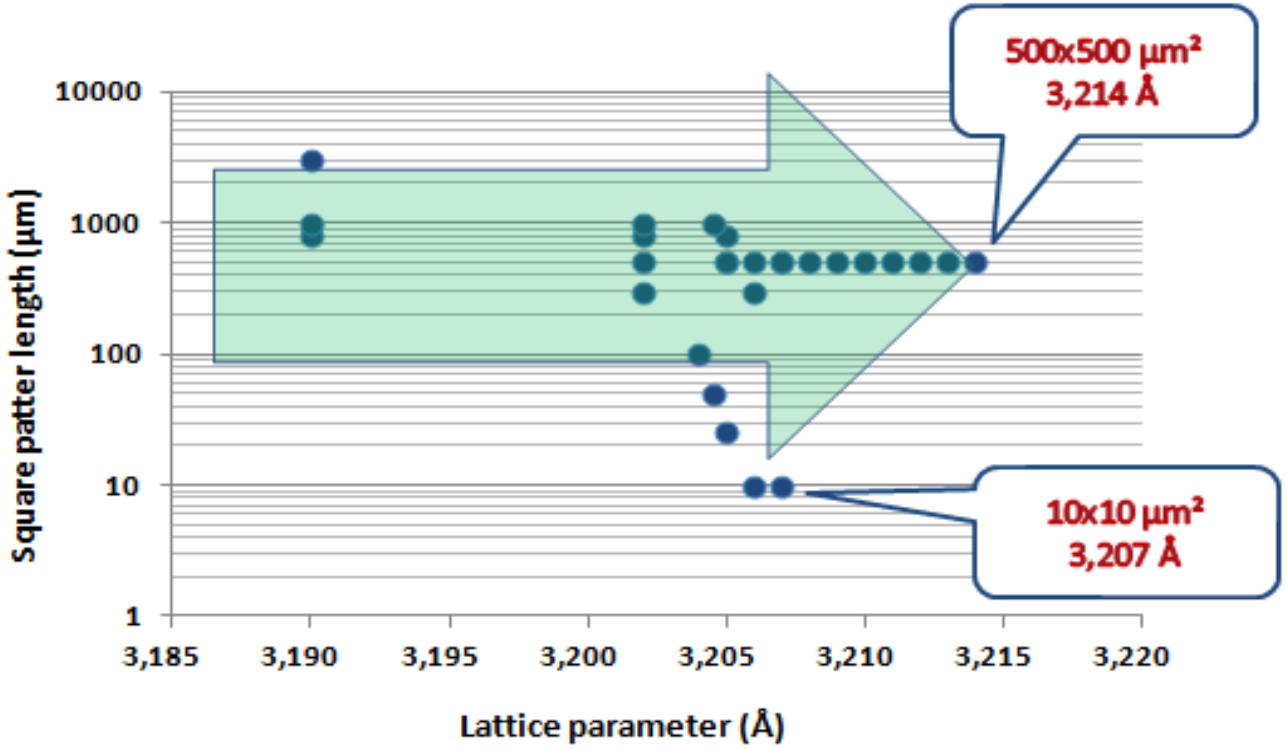


Legend:

- Sapphire
- GaN
- Strained InGaN (Ga face)
- Relaxed InGaN (Ga face)
- Relaxed InGaN (N face)

Towards high lattice parameters: 3,214 Å for 500x500 µm² patterns





- InGaNOS substrates equivalent up to 7% fully relaxed InGaN Templates

InGaNOS proof of value at microLEDs level

- **What we need to demonstrate:**

- Indium incorporation dependence with lattice parameter

- More than 25% Indium incorporation in Quantum Wells

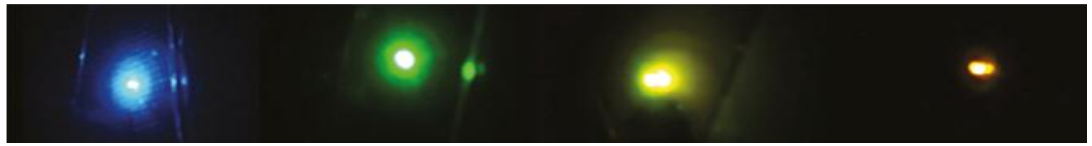
- Demonstration of first full InGaN red microLEDs

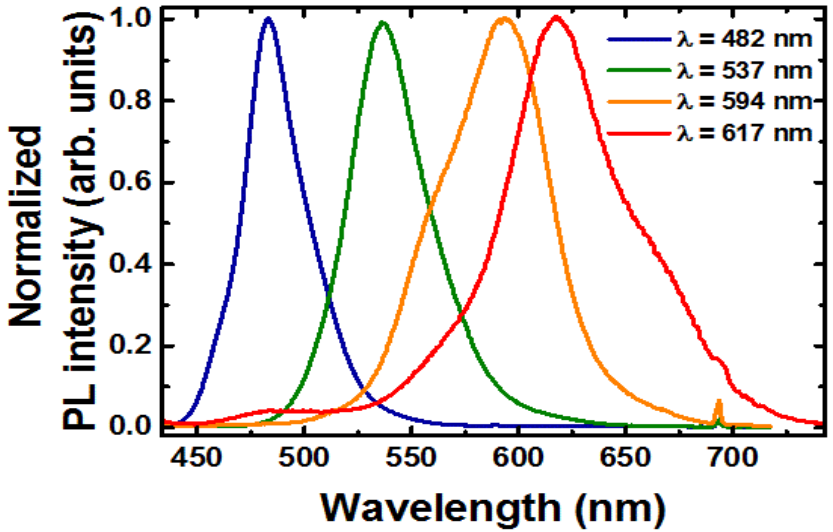
PART 2

First red microLEDs

In incorporation dependence with lattice parameter

- Co-loaded InGaNOS substrates with different lattice parameters.
- Same epi growth conditions for n-doped InGaN buffer and InGaN/ InGaN Quantums Wells
- Emission wavelength tuning from blue to red





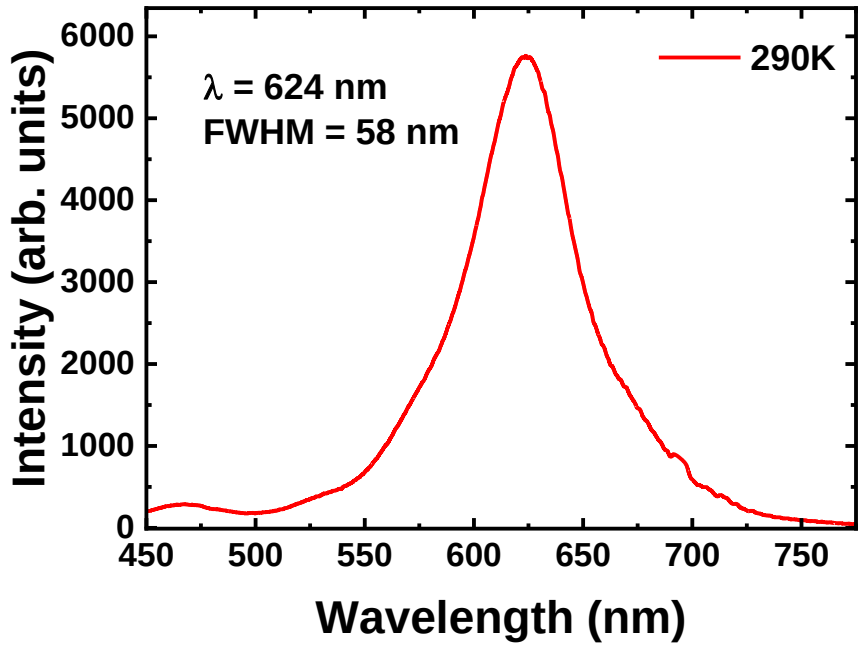
InGaNOS Lattice parameter	λ peak	FWMH
3.190 Å	482nm	33nm
3.200 Å	537nm	41nm
3.205 Å	594nm	60nm
3.205 Å	617nm	63nm

- Indium incorporation dependence with lattice parameter ✓

6.5% red Internal quantum efficiency (IQE)

- Optimized growths conditions focused on red emission

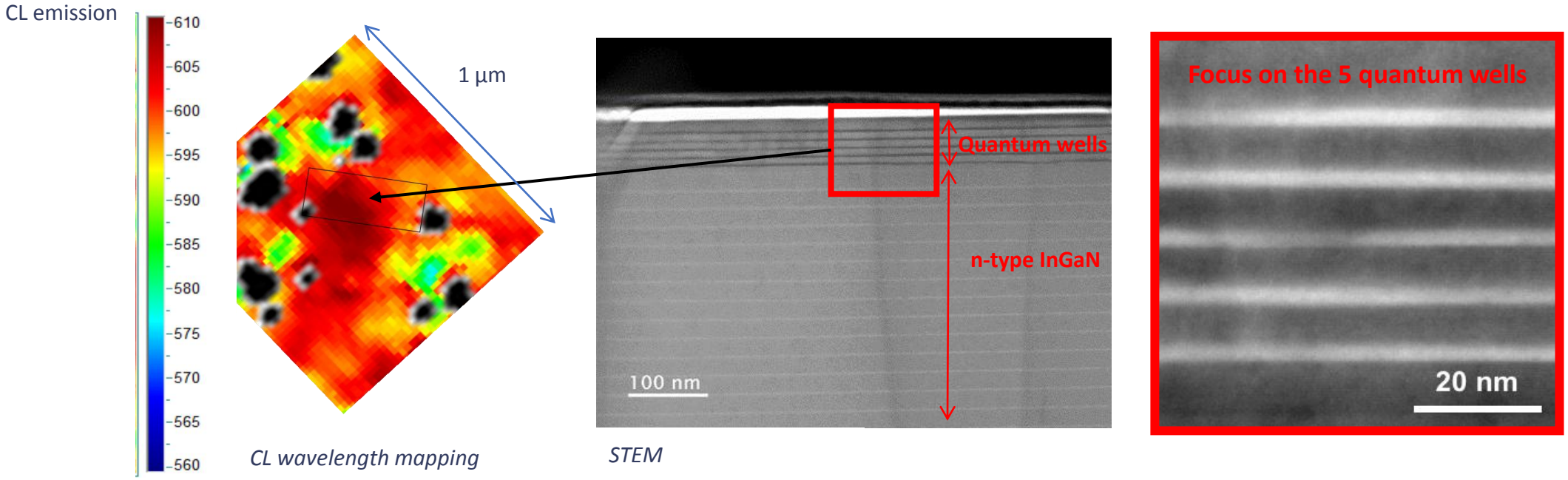
- Central emission wavelength at 624 nm with FWHM = 58 nm at room Temperature



- 6,5% IQE is at the state of the art for InGaN based planar LEDs

Up to 39% Indium in quantum Wells !

- Coupled characterizations between cathodoluminescence (CL) and scanning transmission electron microscopy (STEM)



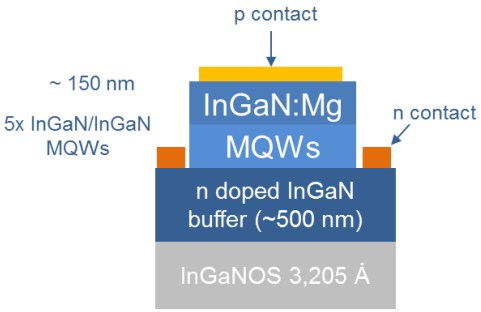
CL wavelength mapping

STEM

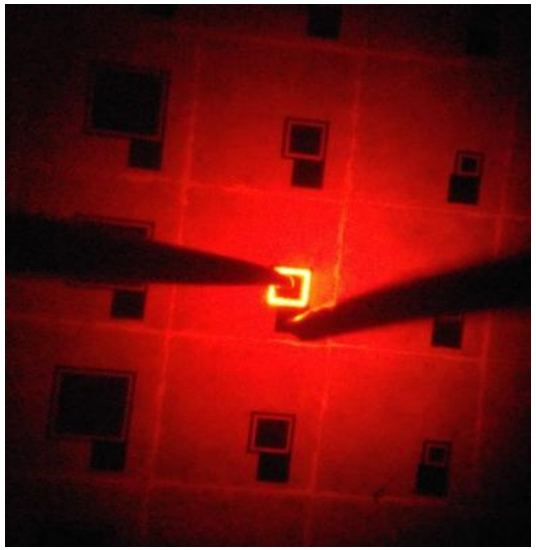
- Homogeneous Quantum Wells thickness of red emission
- 39% In content (determined by GPA analysis) vs 25% limit on std GaN substrate ! ✓
- demonstration that strain release is the good option to increase In content

First red micro-LED

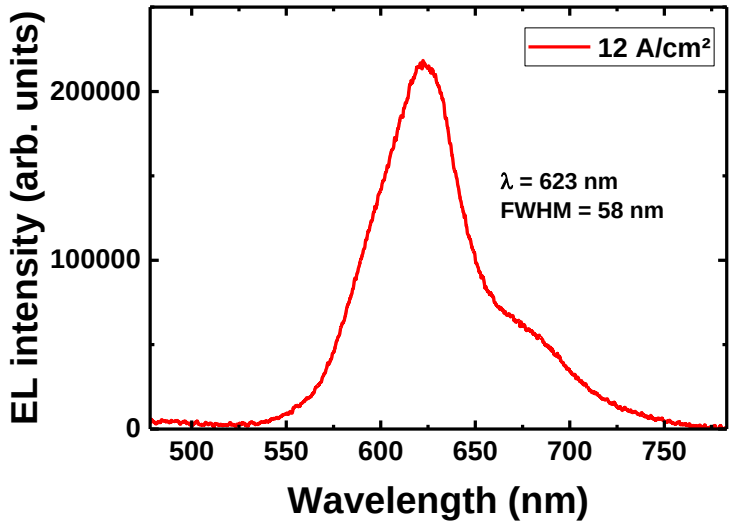
- Emission @ 623 nm at 12 A/cm²



50x50 µm²



Picture from the front side
Emission is from the back side



- Demonstration of first red full InGaN 50x50 µm² ✓

PART 3

Conclusion & perspectives

InGaNOS proof of value at microLED level

- InGaNOS enables whole visible range emission with full InGaN structures
- InGaNOS enables In content up to 40% in QWs
- Full InGaN red micro-LED is demonstrated

2 axis of development

- InGaNOS R&D line conversion in 150 mm
- 150 mm InGaNOS sampling to major LED and display makers
- Demonsration of 5% EQE red microLED

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