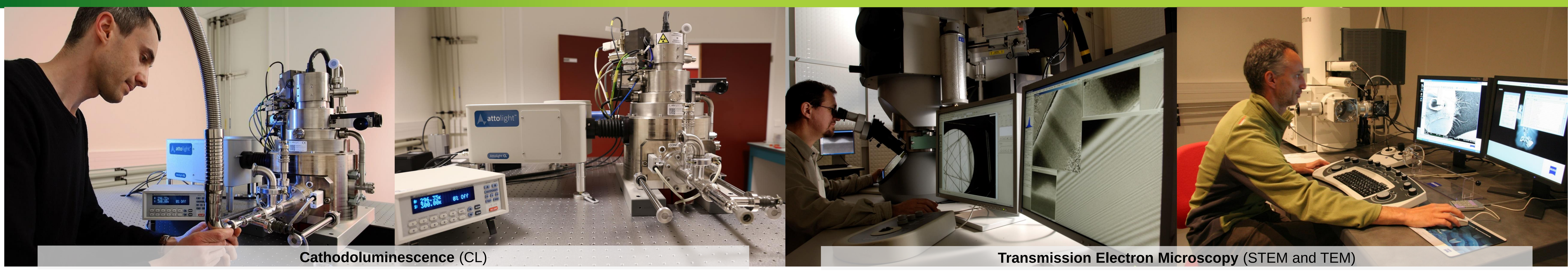
J. Roque, S. David, N.Rochat, F. Bertin, N. Gambacorti

SPATIALLY CORRELATED CATHODOLUMINESCENCE AND TEM OF INGAAS QUANTUM WELL GROWN ON SILICON



Cathodoluminescence (CL)

Transmission Electron Microscopy (STEM and TEM)

Planar growth of InGaAs quantum well [1]

Sample

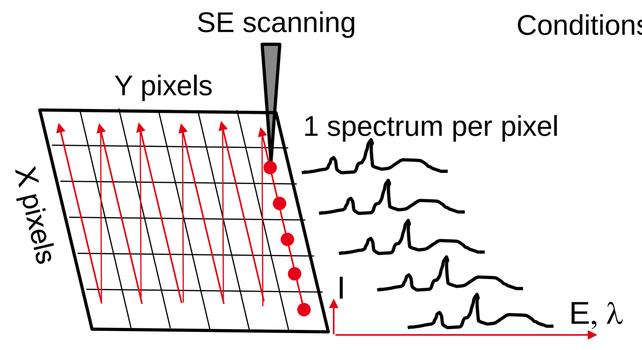
Blanket films

6nm InGaAs/AlAs quantum well/barrier

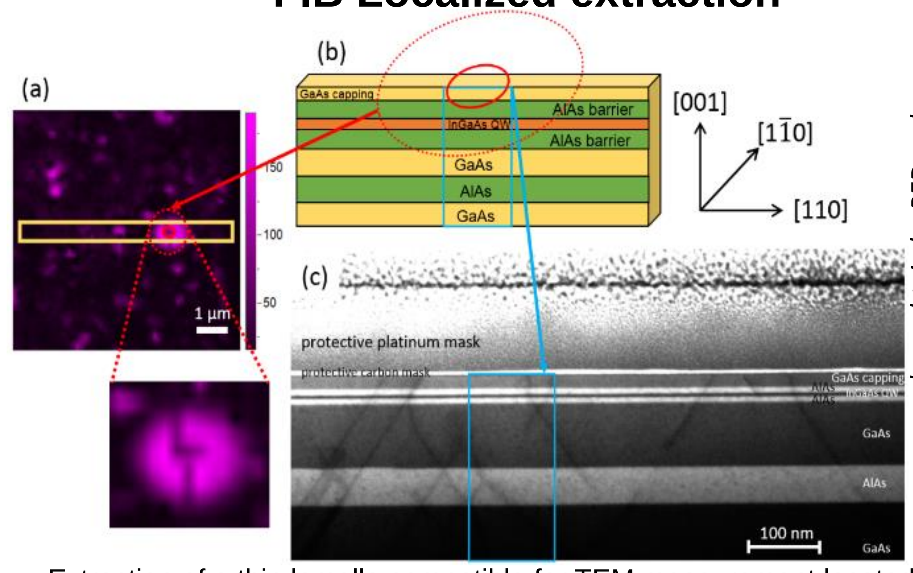
Applied Materials MOCVD
300mm Si (001) substrates.

Before growth :
deoxidization in a SiConi^{TM} chamber with NF_3/NH_3 remote plasma + high temperature thermal annealing under H_2
→structure atomic steps at the surface.

CL hyperspectral mapping



FIB Localized extraction

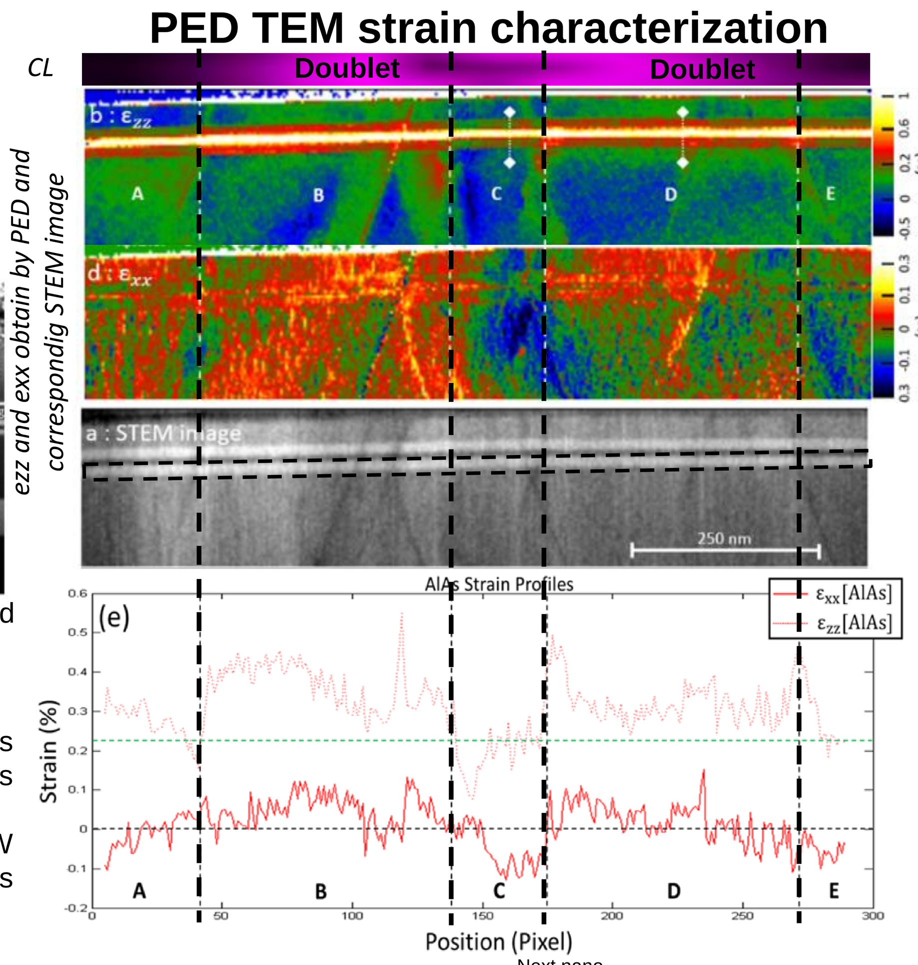


Extraction of a thin lamella compatible for TEM measurement located across a donut where a doublet is detected.

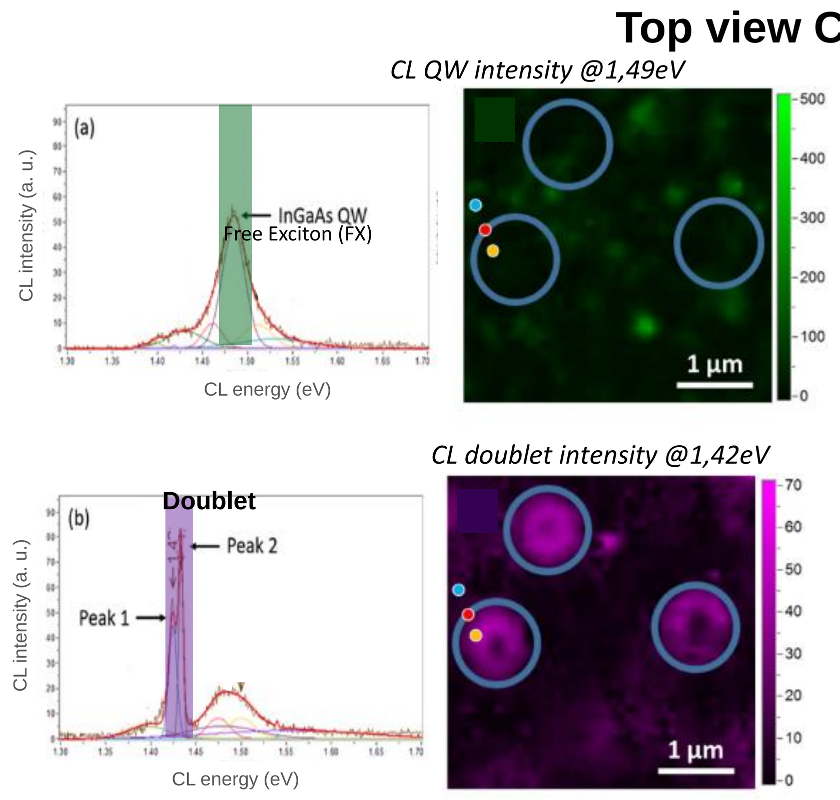
AlAs strain luminescent areas have different strain states
→ Doublet is located at different barrier strain states

Probe size to big to characterize strain inside the QW
→ Need GPA analysis

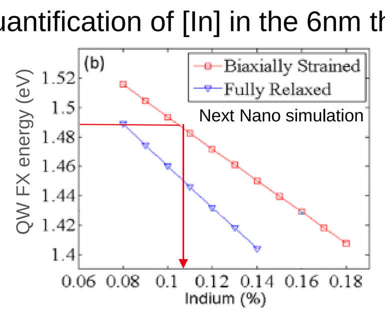
PED TEM strain characterization



Top view CL mapping



Quantification of [In] in the 6nm thick QW



FX_{QW}=1,49eV ⟹ $[In]_{nextnano}$ =11%

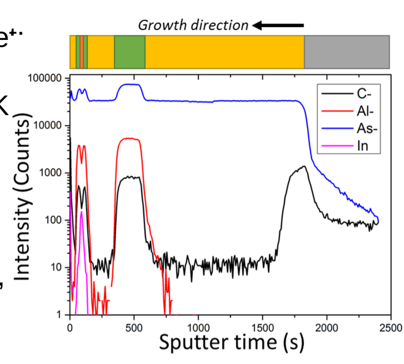
Next nano (6nm, biaxially strained)

Detection of a thin doublet spatially localized @ 1,42eV characterized by a donut shape, a central extinction and ΔE=9meV

Temperature and current study of the doublet:
Saturation for high current
Quenching at low temperature (20K)
→extrinsic defect band due to contaminant

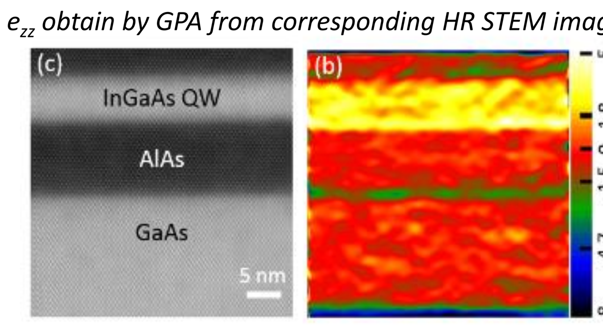
Tof SIMS show high [C] in the barrier, only

ΔE=9meV compatible with a FX-BX doublet, the QW exciton bounded to carbon located outside the QW.

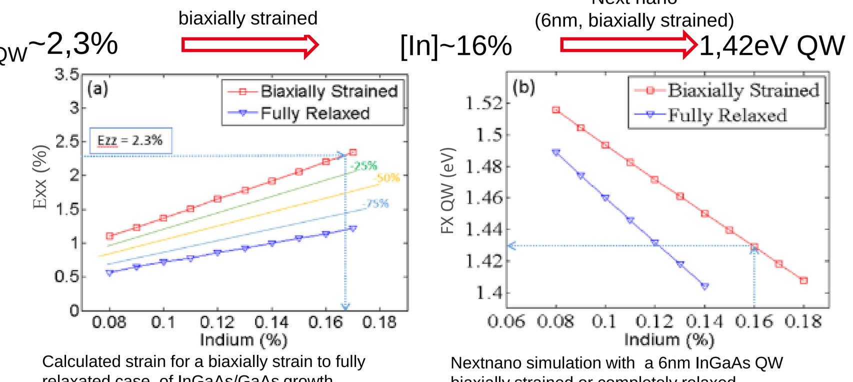


GPA TEM strain characterization

e_{zz} obtain by GPA from corresponding HR STEM image



ε_{QW}~2,3% ⟹ (biaxially strained) [In]~16% ⟹ (Next nano (6nm, biaxially strained)) 1,42eV QW FX emission



Calculated strain for a biaxially strain to fully relaxated case of InGaAs/GaAs growth

Nextnano simulation with a 6nm InGaAs QW biaxially strained or completely relaxed

Nature of the doublet is elucidated as a Free exciton (FX) – Bounded exciton (BX) of the QW due to carbon located in the barrier. But the spatial shape of this emission and its FX shifted energy need local measurement of [In] and/or strain to be understood.

Spatially resolved characterization show that doublet is located in region with particular barrier strain, higher [C] in the barrier and higher [In] in the QW.
These observations are coherent with the low energy luminescent doublet circular feature observed on the sample.

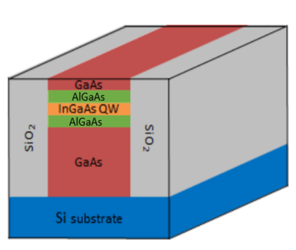
Selective epitaxy growth of InGaAs quantum well [2]

Sample

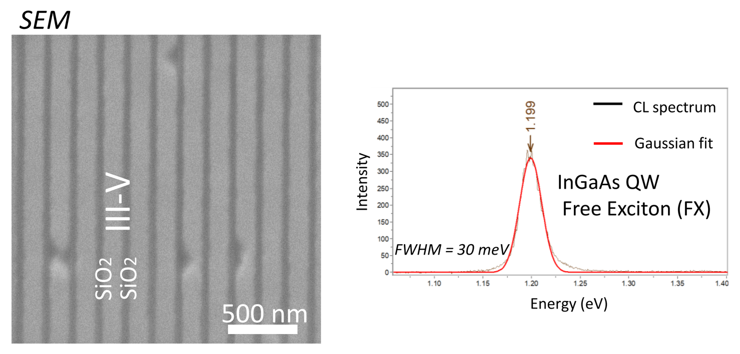
GaAs growth in SiO2 etched pattern on Si

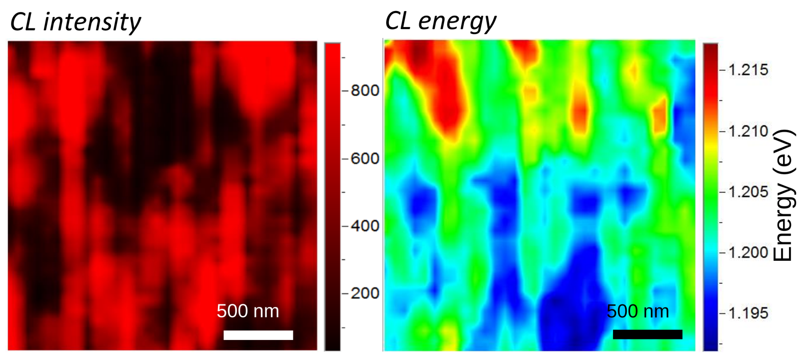
QW : 10nm $In_{0.3}Ga_{0.7}As$
Barriers : 8nm $Al_{0.5}Ga_{0.5}As$

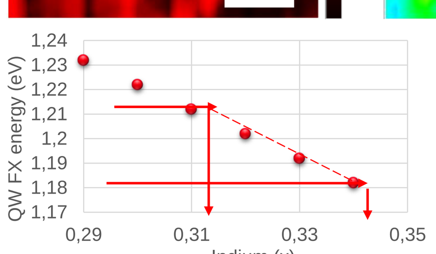
Applied Materials MOCVD
300mm Si (001) substrates.



CL top view mapping



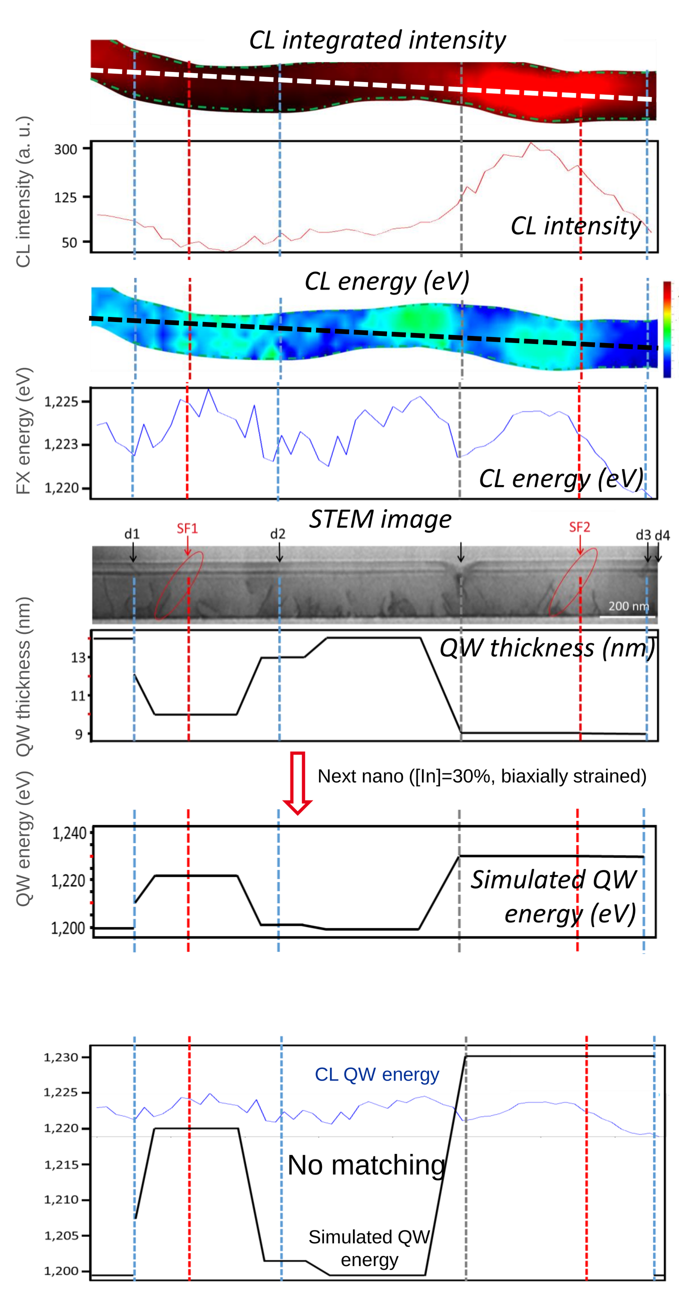




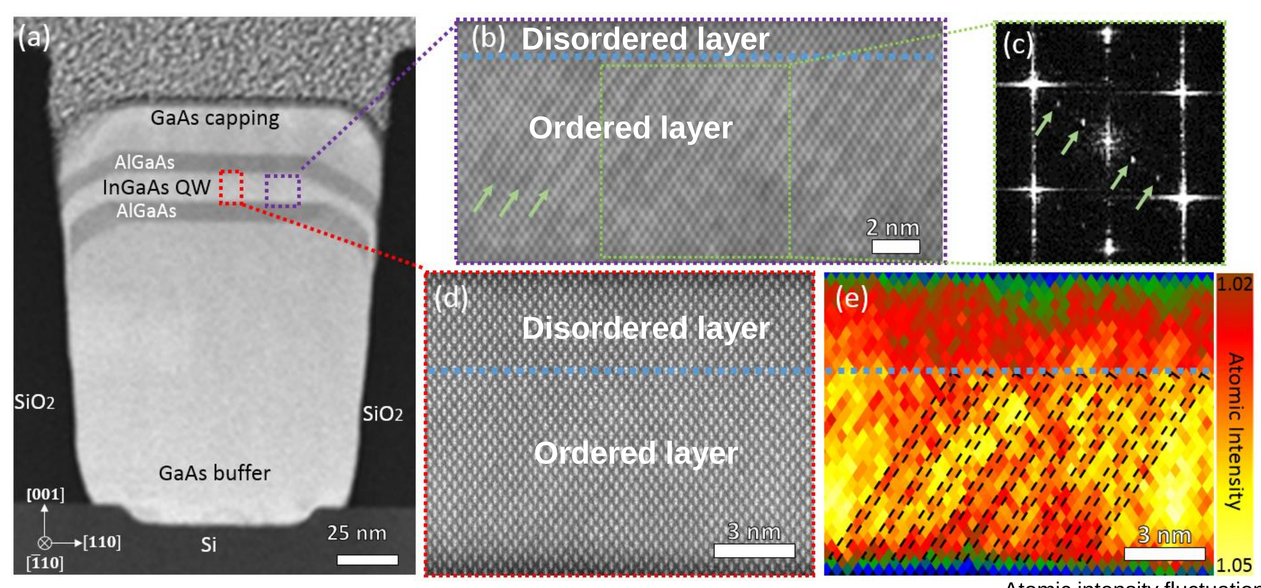
Short weak luminescent segment @1,18-1,21eV
→ [In]~32%+/-1,5%

Very different from XRD [In]~28%

CL STEM correlation



HRSTEM & CL correlation



Extra spot of FFT
→ Triple period chemical ordering

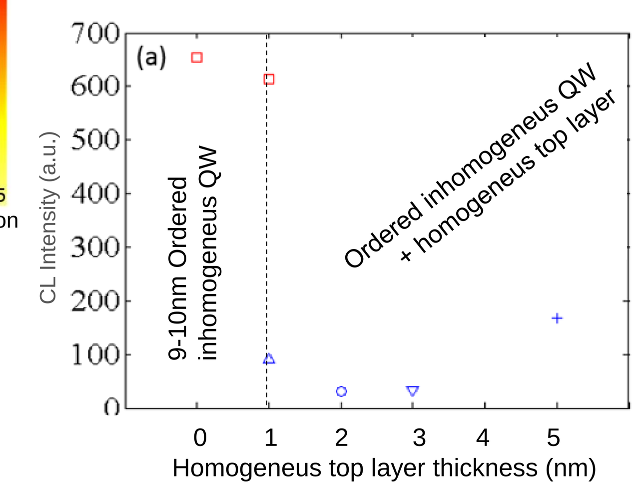
1 plan every 3 is 15% depleted in [In]

QW composed of 2 layers :
- **a 9-10nm inhomogeneus, ordered, layer at the bottom**
- **a homogeneous layer of 0 to 14nm on the top**

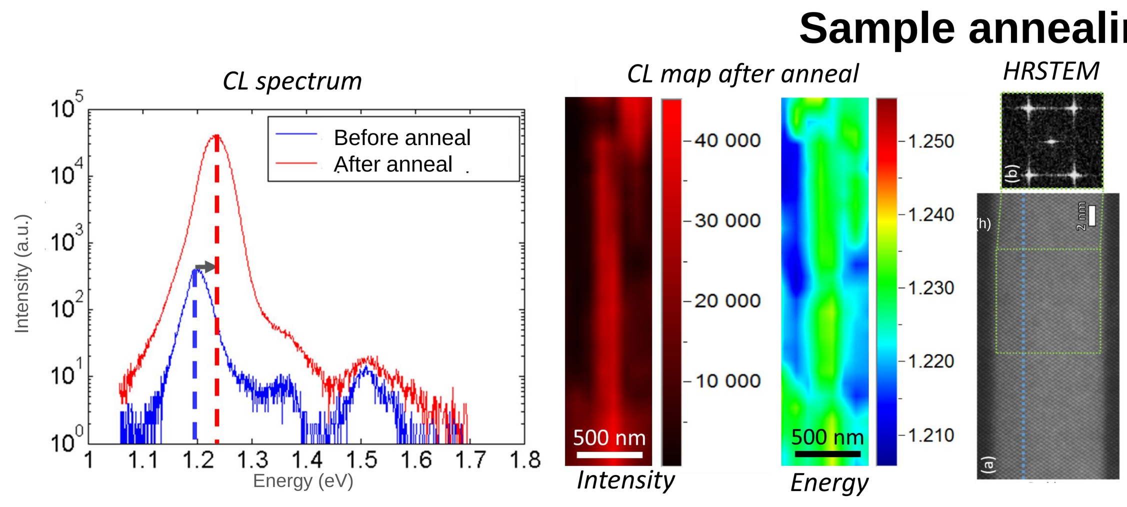
Impact of ordering on luminescence :
- unperfect crystal → low intensity
- lower bandgap energy

homogeneous top layer on luminescence → reduces radiative transition probability

Ordering is not a stable phase → 300°C anneal to remove it



Sample annealing



After anneal:
- disappearance of extra spot → no more ordering
- longer CL segment and higher CL intensity (x100)
- higher CL energy @1,23eV
simulation→[In]=29%+/-1,5%
well correlated with 28% by XRD

Correlation between QW thickness and energy cannot be done assuming a biaxially strained and constant [In] QW. Need local measurement of [In] and/or strain to understand local variations of luminescence intensity and energy.

The 2 layers QW structure explain the mismatch between QW thickness and energy observed by CL-STEM correlation. Chemical ordering in the QW explain the low CL intensity and the discrepancy between [In] quantification from XRD and simulation of QW FX energy. Annihilation of ordering allow the full understanding of the structure.

Acknowledgment

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References

[1] J. Roque, G. Beainy, N. Rochat, N. Bernier, S. David, J. Moeyaert, M. Martin, T. Baron, and J.L. Rouvière., *Journal of Vacuum Science & Technology B* **36**, 042901 (2018);.

[2] J. Roque, B. Haas, S. David, N. Rochat, N. Bernier, J. L. Rouvière, B. Salem, P. Gergaud, J. Moeyaert, M. Martin, F. Bertin, and T. Baron, *Appl. Phys. Lett*. **112**, 202104 (2018).