



The European Synchrotron

Nano-analysis of optoelectronic materials in structured semiconductors

Valentina Bonino
ID16B nano-analysis beamline
ESRF, Grenoble, France

1. How nano-analysis at ID16B@ESRF can help?

2. Techniques available

3. Application cases:

- Carrier doping homogeneity and optical properties in Co-doped ZnO nanowires
- Phase structure and optical properties in heterostructures
- Segregation in GeSn alloys

LOCAL NON-IDEALITIES IN SEMICONDUCTOR SYSTEMS

TO BUILD EFFICIENT DEVICES:

1. Understanding of the Fundamental mechanisms
2. Growth control and efficiency
3. High-quality structure
4. Correlation among composition, structure, and physical properties
5. Device fabrication and processing



WHY NANO-ANALYSIS?

- LOCAL PROPERTIES are important for the DESIGN, TUNING AND FUNCTIONING of SYSTEM BASED ON MICRO- OR SUBMICRO-METRIC FEATURES

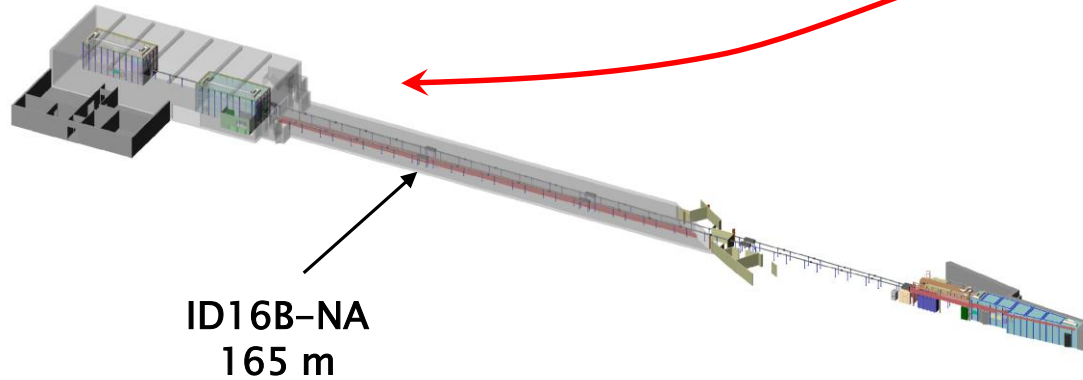


WHY SYNCHROTRON?

- Combination of sophisticated techniques with an high brilliance source. Multi-modal analysis with high spatial resolution and atomic selectivity.



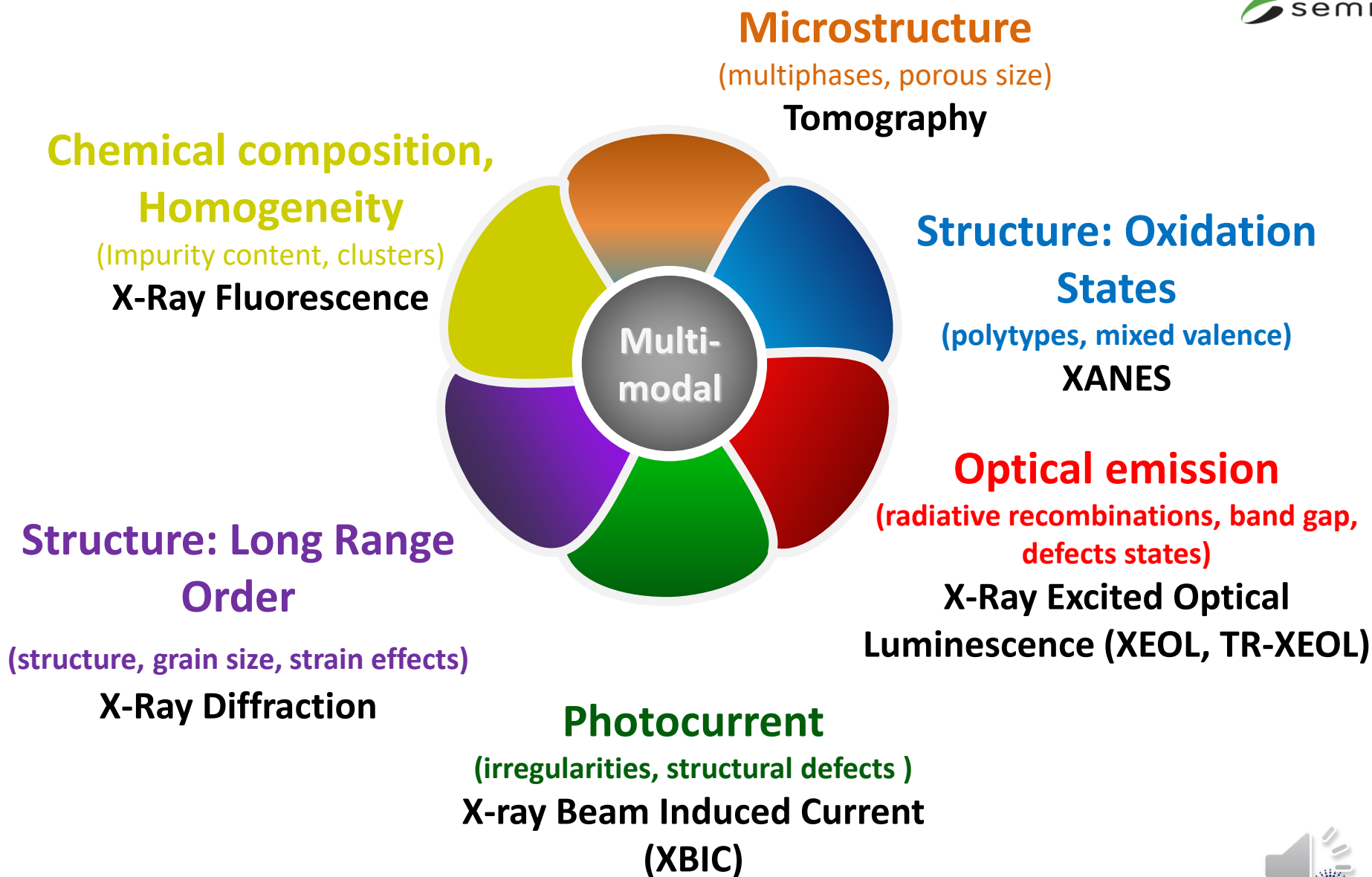
ID16B BEAMLINE AT THE EUROPEAN SYNCHROTRON (ESRF)

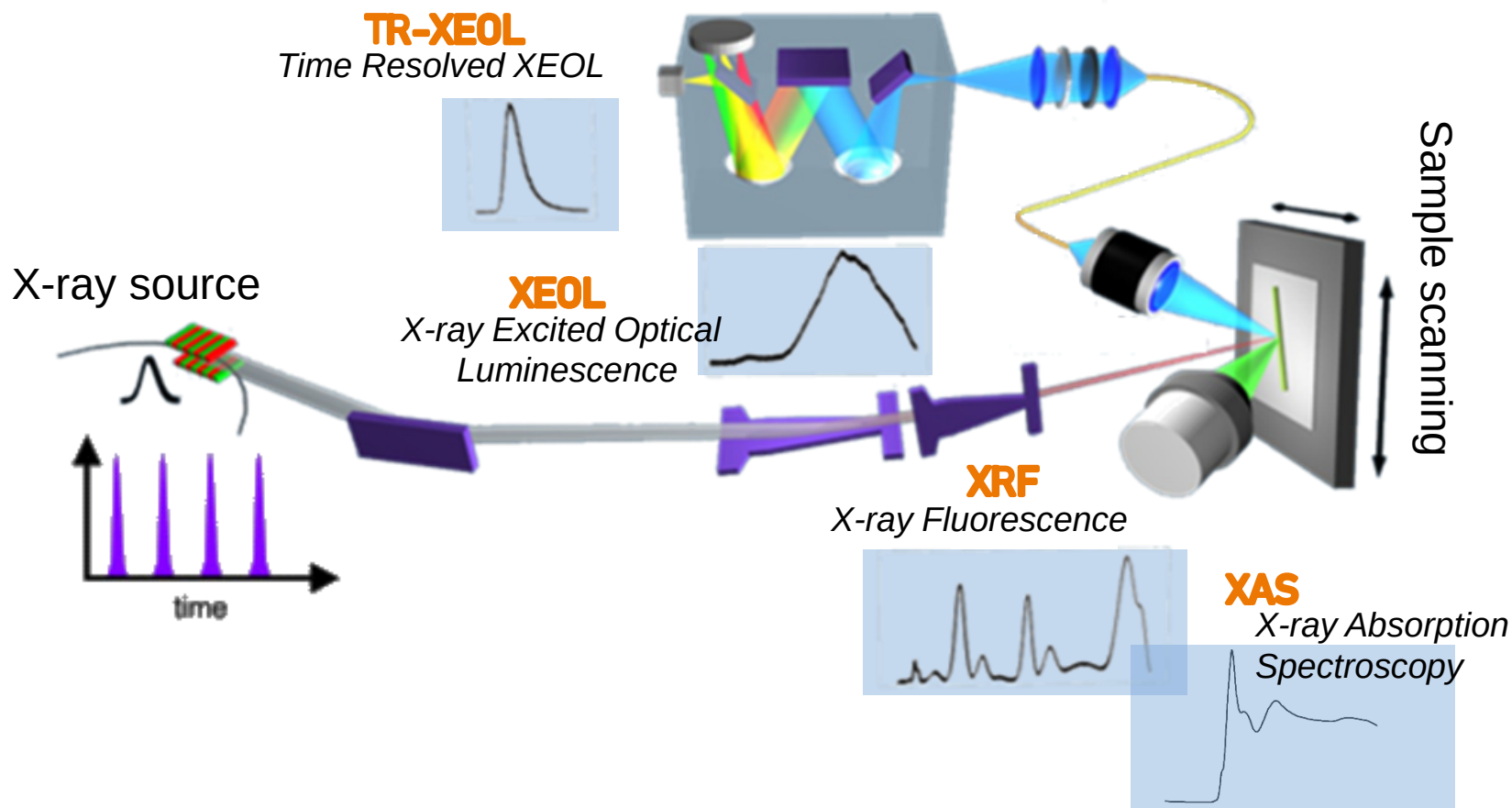


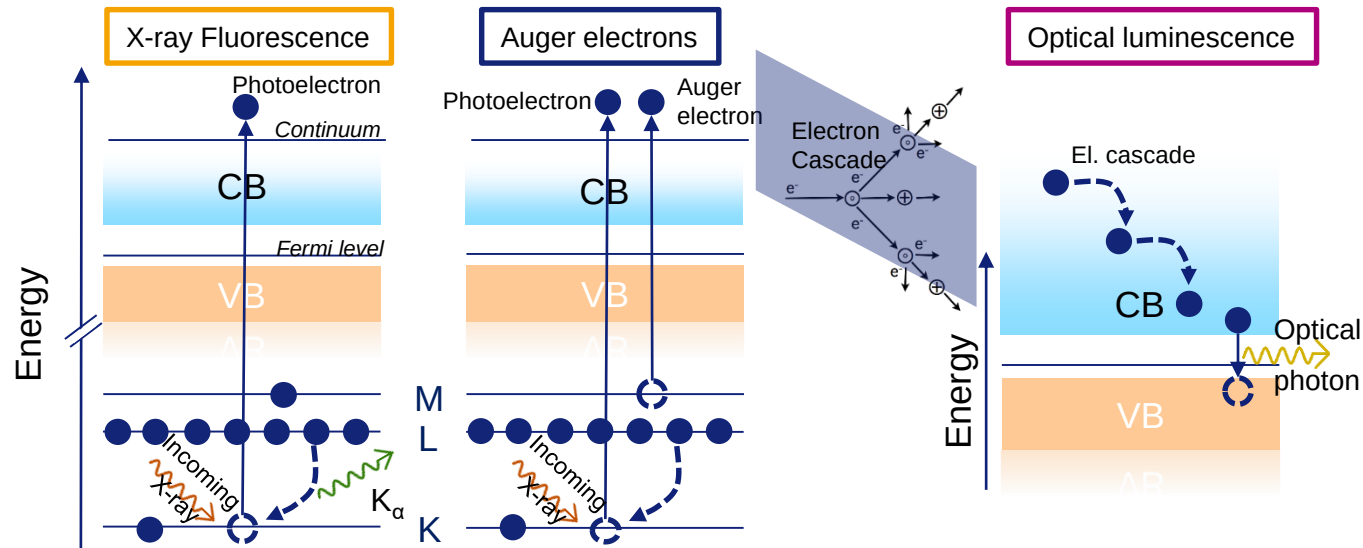
ID16B: nanofocus multimodal beam

Beamline responsible: Julie Villanova, Scientist: Valentina Bonino

- Beam size: 50 x 50 nm²
- Energy range: 5 – 34 keV
- Photon flux: 10⁹ – 10¹³ ph/sec
- Monochromaticity: $\Delta E/E$: 10⁻² – 10⁻⁴
- Beam operation modes: pink and monochromatic
- Techniques: XRF, XAS, phase contrast tomography, XRD, XEOL, XBIC
- Studies: *in situ*, *operando* & time-resolved experiments







Absorption of X-ray and emission of characteristics X-ray photons and of photo- and Auger electrons.

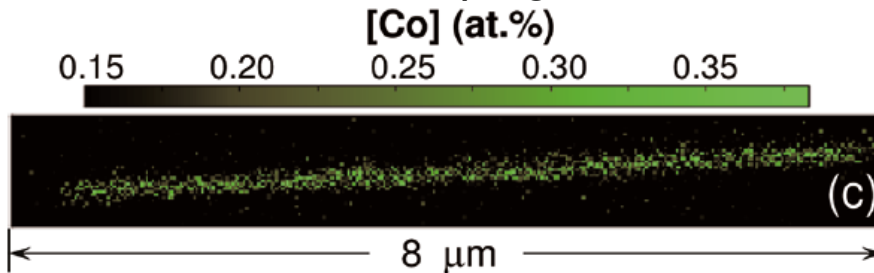
Scattering of photo- and Auger electrons generates secondary electrons in a cascade effect. Once electrons reach the CB, they can relax radiatively emitting optical photons.

Carrier doping of ZnO is of interest in the fabrication of Qubits and single photon sources

Color centers in ZnO induce fast emission in the visible

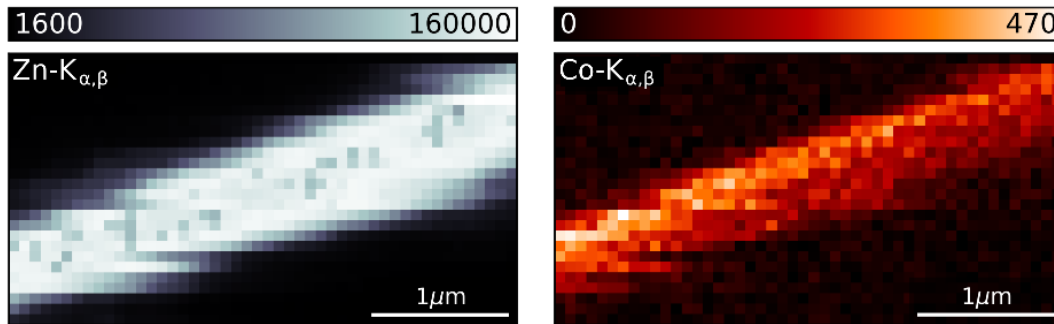


XRF of the cobalt doping distribution in ZnO nanowire

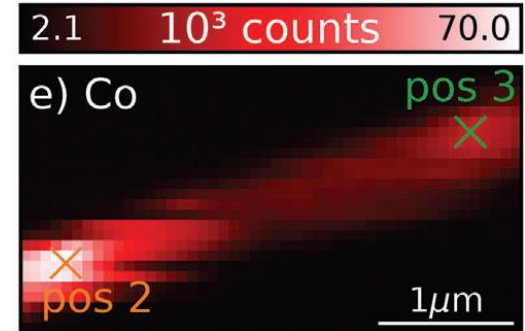


How optical emission and dopant distribution are related?
What is the relaxation path of the dopant?

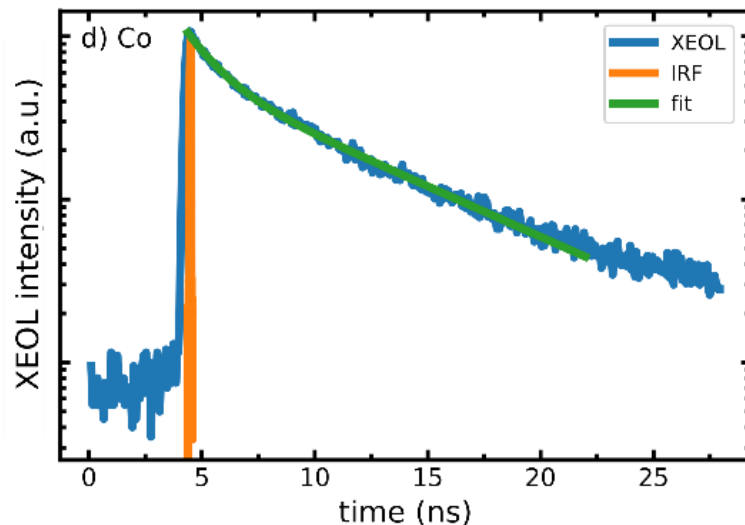
XRF



XEOL (Co)



TR-XEOL

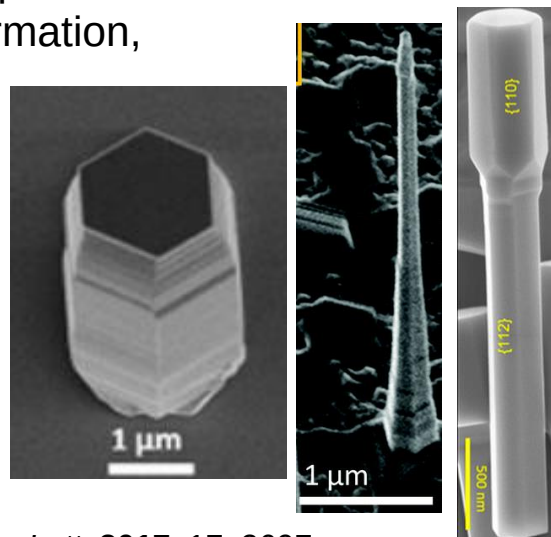


Two decay dynamics:

$\tau_{slow} \sim 7$ ns energy transfer from the ZnO host

$\tau_{fast} \sim 1.7$ ns **New fast relaxation path!**
Accessible by X-ray excitation and its origin might be linked to the direct excitation of the Co atoms

Crystal structure and facets play an important role in the NW heterostructure formation,



Nano Lett. **2017**, 17, 2697

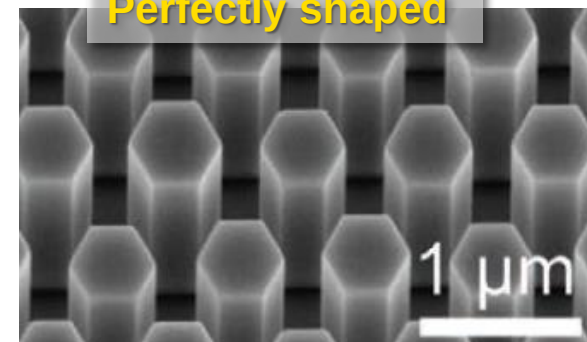
Nanoscale **2017**, 9, 13554

ACS Nano **2018**, 12, 10, 10374-10382

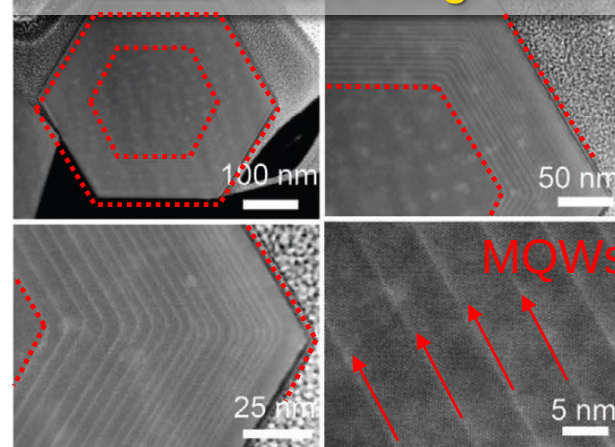
Nanowires (NWs) heterostructures with InGaAs/InP multi-quantum wells (MQWs)

With SAE

Perfectly shaped



Heterostructure integration



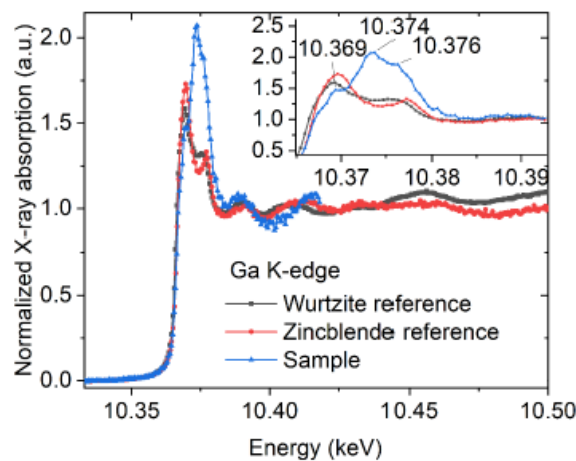
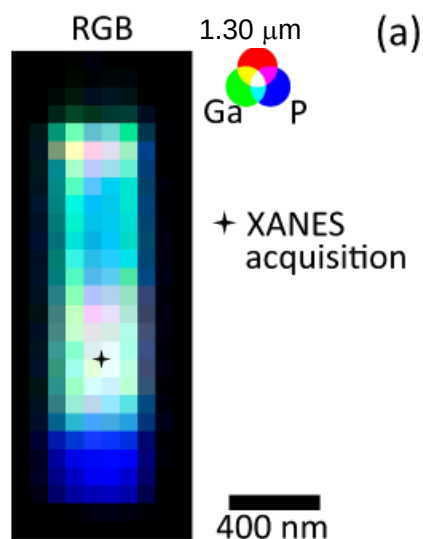
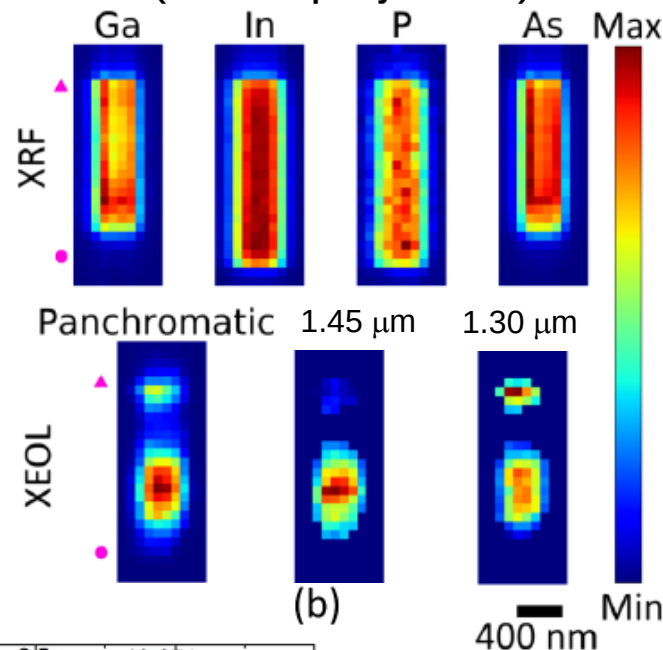
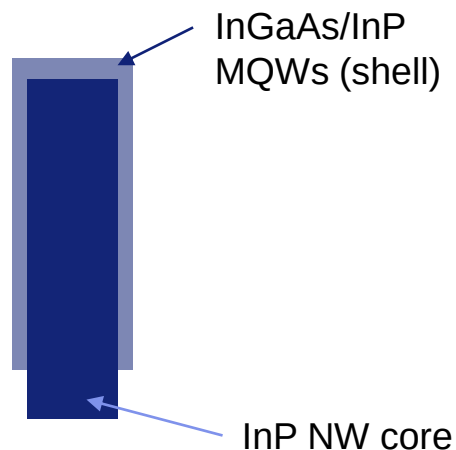
Adv. Funct. Mater. **2022**, 32, 2103057

MQWs grown on polytypic wurtzite and zincblende

What is the relation between optical emission/phase distribution?

Composition and optical emission (lateral projection)

Heterostructure cross section



Proc. SPIE12991 **2024**, Nanophotonics X,
129911I

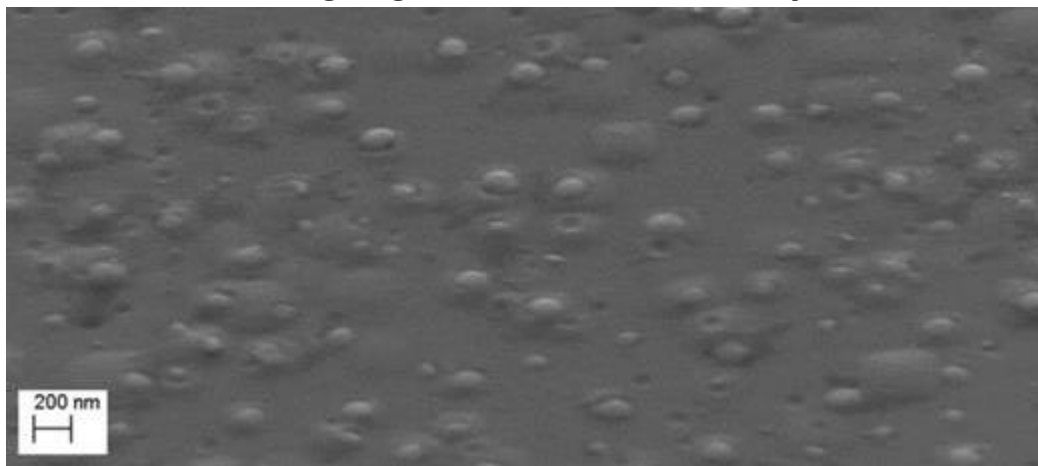


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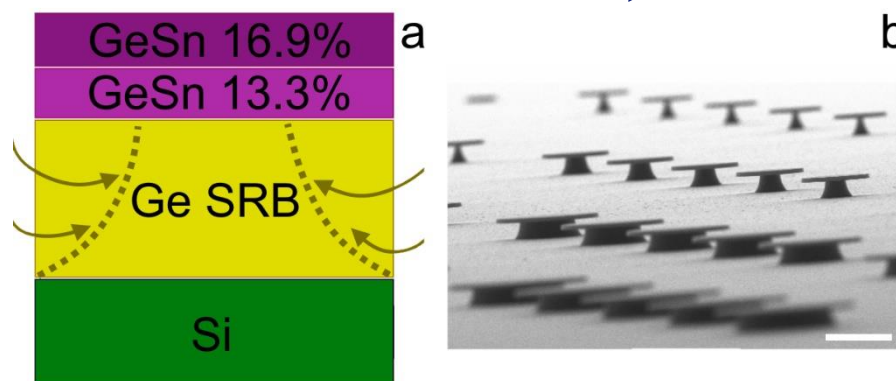
Thermal annealing above about 230 °C induces Sn segregation in GeSn alloys



J. Appl. Phys. **2016**, 120, 145303

**Does micro-structuring
improve the resistance
to segregation?**

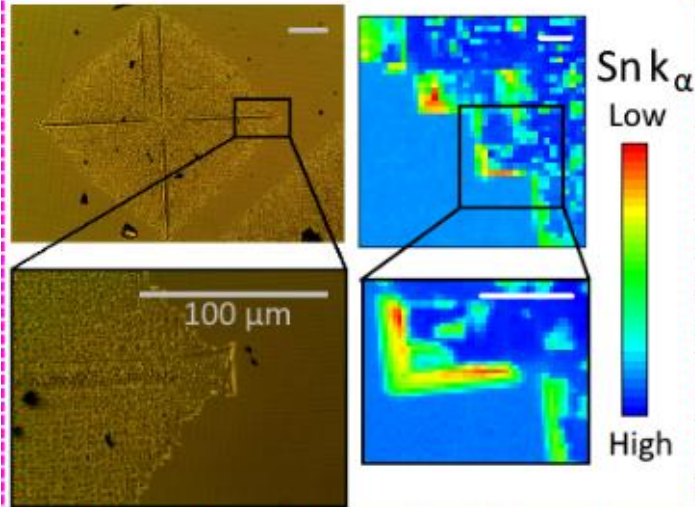
From layers to micro-structured layers



ACS Appl. Mater. Interfaces **2022**, 14, 22270–22277

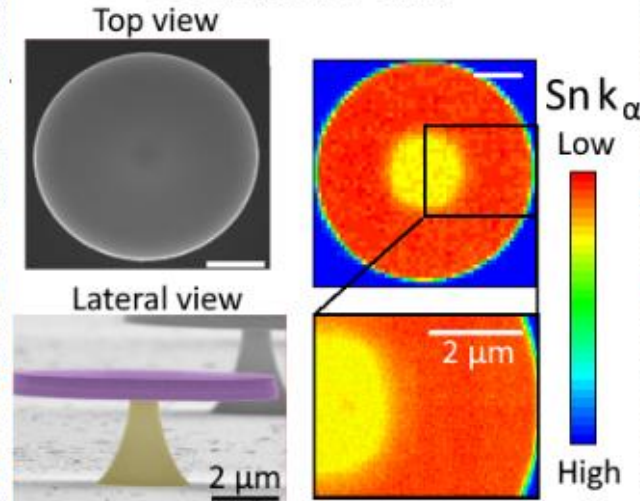
Segregation

GeSn Blanked layer



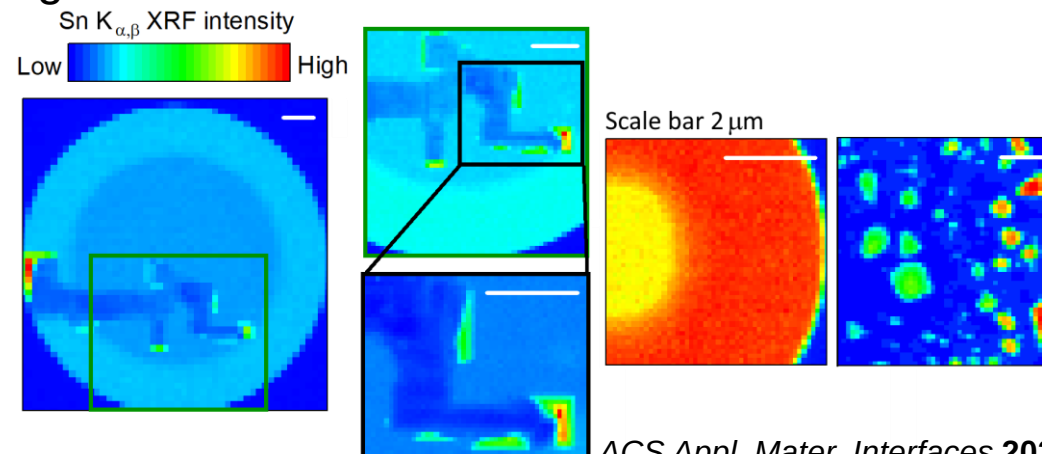
Stable

GeSn micro-disk

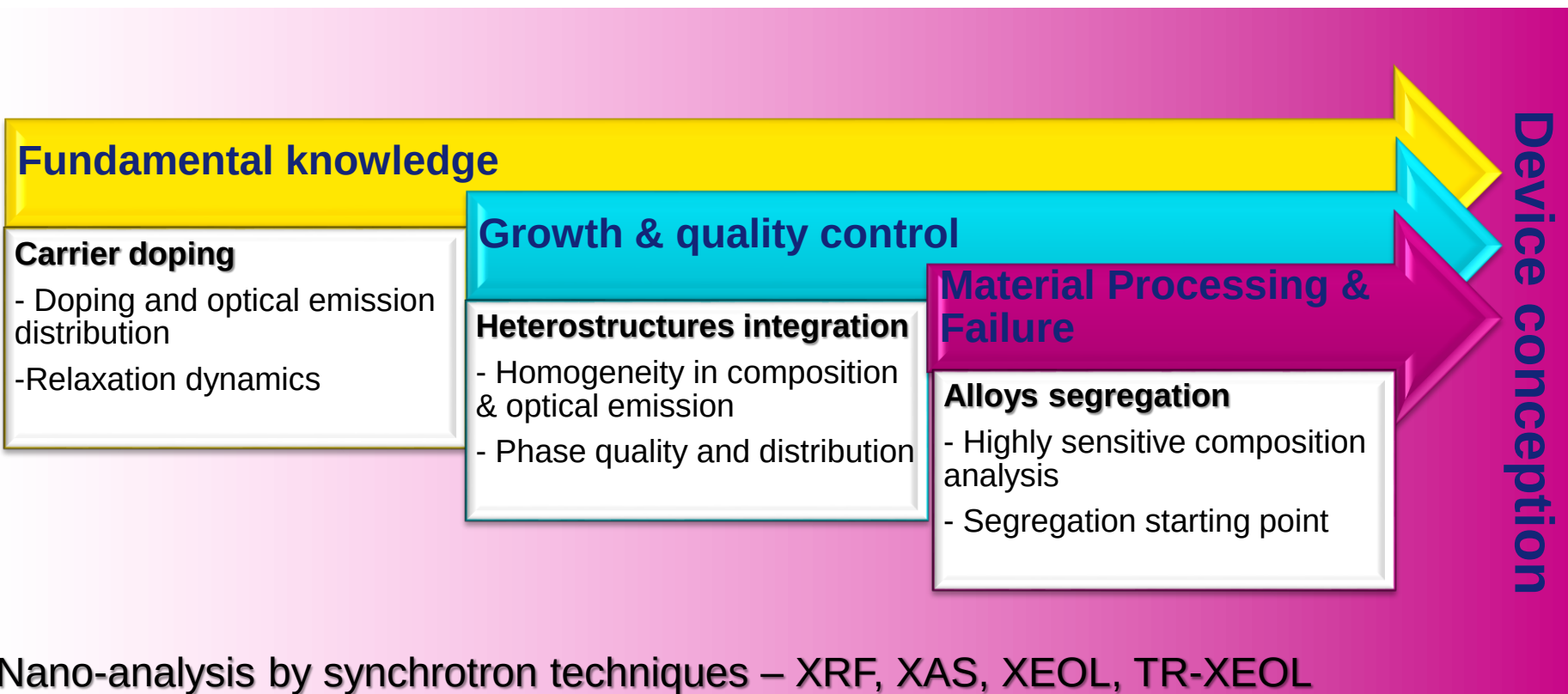


Annealing at 350 °C

Segregation: initiation and isolation



ACS Appl. Mater. Interfaces **2022**, 14, 22270–22277





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Thank you for your attention

If you have a proposition, do not hesitate to contact me: valentina.bonino@esrf.fr

Deadlines call for proposal: March and September.

Visit ID16B website at <https://www.esrf.fr/UsersAndScience/Experiments/XNP/ID16B>