

Synthesis of quantum dots in III-V nanowires

Duration: 6 months starting from March
Salary ~600 EUR/month
Supervisor: Federico PANCIERA
Laboratory: Centre for Nanoscience and Nanotechnology (C2N), U. Paris-Saclay/CNRS
Web: <https://elphyse.c2n.universite-paris-saclay.fr/en/>
Contacts: federico.pancier@c2n.upsaclay.fr

Context of the project: Semiconductor nanowires (NWs) exhibit unique properties that make them potential building blocks for a variety of next generation devices such as biosensors, solar cells, transistors, quantum light sources and lasers. In order to take advantage of the physical properties of NWs, it is crucial to control their geometry, crystal structure and doping. This goal will ultimately be achieved by a deep understanding of the growth mechanisms. The most common growth technique is the vapor-liquid-solid (VLS) method, where a liquid metal droplet catalyzes the growth of a solid NW from gas phase precursors. In this growth mode, the droplet plays a fundamental role in determining the structure of the nanowire, and the remarkable range of structures enabled by VLS can be thought of as the result of engineered changes to the droplet.

For example, growth of III-V semiconductor NWs using the VLS method can result in crystal structures different from their bulk phase. In GaAs NWs stable zincblende (ZB) phase coexists with metastable wurtzite (WZ) structure resulting in NWs having a mixed-phase structure. Remarkably, the valence and conduction bands of the two phases are misaligned so that small sections of one phase within the other effectively confine charge carriers. Controlled switching between the two phases enables the synthesis of novel heterostructures, crystal-phase quantum dots (CPQD), with exceptional properties and potential applications in photonics [1] and quantum computing [2,3]. In contrast to compositional heterojunctions, **CPQDs have intrinsically abrupt interfaces and hence do not suffer from alloy intermixing at the interface**, which hampers precise control of the electronic properties in compositional heterostructures.

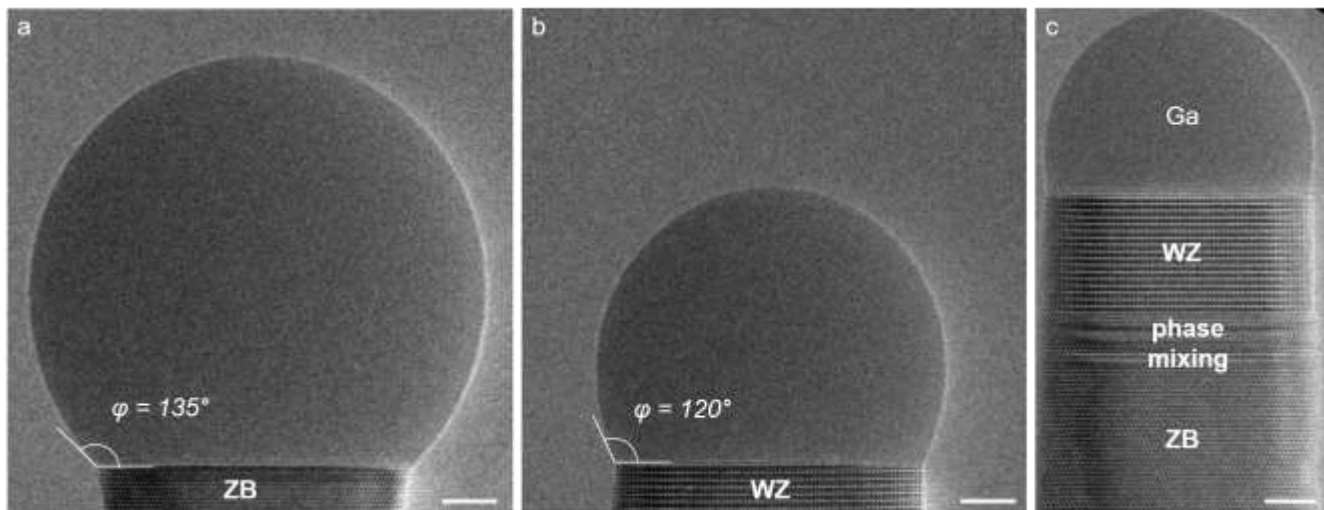


Figure 1. Impact of contact angle on the phase selection [8]. Images of a self-catalyzed GaAs NW recorded using the NanoMAX *in situ* TEM. The NW was grown by molecular beam epitaxy using the vapor-liquid-solid (VLS) method, where a liquid metal droplet (Ga in this case) catalyzes the growth of a solid NW from material provided from a gas phase. A large contact angle ($\varphi > 125^\circ$) results in the growth of ZB (a), while a small one corresponds to WZ (b). c Shows a NW having segments of the two phases. Scale bars are 5 nm.

Even though CPQDs were first discovered more than ten years ago, their technological application has been severely limited by the difficulty of needing precise control over their growth. In particular, the physics underlying the phase selection mechanism was poorly understood. Only recently, thanks to *in situ* transmission electron microscopy (TEM), we started to shed light on this mechanism. *In situ* TEM provides unparalleled imaging resolution and allows the capturing of the growth dynamics [4,5,6] and the effect of growth parameters in real-time. Using this technique, we demonstrated that **the sole parameter determining the phase selection is the contact angle** between the droplet and the NW interface (Figure 1) [7,8].

The goal of this project is to develop innovative strategies for controlling the contact angle of III-V nanowires to achieve unprecedented precision in crystal phase control and fabrication of CPQDs. This will be accomplished through a combination of in situ real-time TEM investigations and ex situ growth using a conventional MBE setup.

Master 2 internship: The successful applicant will actively participate in the *in-situ* experiments and will be in charge of the data analysis. The *in situ* experiments will be conducted using the MBE growth method in the NanoMAX TEM [[Video](#)]. The analysis will be carried out by developing dedicated image-processing algorithms able to extract relevant geometric parameters (i.e. droplet size, contact angle, crystal phase) from each image. The resulting data will be used to correlate the changes of contact angle to phase switching and develop a model to predict the crystal phase for different growth conditions.

This work could be extended to a Ph.D.

Candidate profile: Highly motivated candidates enrolled in a master's degree or equivalent, with a background in physics, materials science or engineering. Prior knowledge in programming (possibly Python) would be highly appreciated.

Application procedure: For additional information about the project and/or the recruitment process, please contact Federico PANCIERA (federico.panciera@c2n.upsaclay.fr). The candidate should include a CV.

References

- ¹ Akopian et al. Crystal phase quantum dots. *Nano Lett.* **2010**, *10* (4), 1198-1201.
- ² Hastrup et al. All-optical charging and charge transport in quantum dots. *Scientific Reports* **2020**, *10*(1), 1-6.
- ³ Li et al. Location Qubits in a Multiple-Quantum-Dot System *Nano Lett.* **2024**, *24*, 18, 5656–5661
- ⁴ Panciera et al. Synthesis of nanostructures in nanowires using sequential catalyst reactions. *Nature materials*, **2015**, *14*98, 820-825.
- ⁵ Panciera et al. Controlling nanowire growth through electric field-induced deformation of the catalyst droplet. *Nature communications*, **2016**, *7*(1), 1-8.
- ⁶ Harmand et al. Atomic step flow on a nanofacet. *Phys. Rev. Lett.* **2018**, *121*, 166101.
- ⁷ Jacobsson, Panciera et al. Interface dynamics and crystal phase switching in GaAs nanowires. *Nature*, **2016**, *531*(7594), 317-322.
- ⁸ Panciera et al. Phase selection in self-catalyzed GaAs nanowires. *Nano Lett.* **2020**, *20*(3), 1669-1675.