Internship proposal for a second-year master student

In-situ TEM Growth of Chiral Tellurium Nanowires on Silicon

Duration: 6 months starting from March
Salary ~650 EUR/month
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Context of the project: Tellurium (Te) is a chiral elemental semiconductor whose atomic structure consists of helical chains (space groups $P3_121$ or $P3_221$), imparting unique electronic, optical, and spin properties. Its quasi-one-dimensional nature yields strong spin–orbit coupling, anisotropic transport, and distinctive optical responses, including non-linear chiral effects such as second-harmonic generation circular dichroism (SHG-CD) in ultrathin nanowires [1,2]. Several growth approaches have been reported, including vapor transport, solution chemistry, and physical vapor deposition. These methods have produced Te nanoribbons or nanowire with good crystallinity and high mobilities of ~400 $cm^2/V{\cdot}s$ and on/off ratios ~10^5 [3]. However, control over nanowire orientation and handedness remains limited, and atomic-scale insights into the growth mechanism are still scarce [3]. Growing Te as free-standing nanowires directly on silicon is an attractive and largely unexplored route. Silicon is the reference platform for integration with existing technologies, its crystalline surfaces offer well-defined orientations that can guide nanowire growth, and free-standing nanowires grow away from the substrate, limiting substrate-induced defects and strain. Understanding how Te nanowires nucleate on silicon, and what determines their growth direction, diameter and chirality, is therefore a key step towards their use in devices.

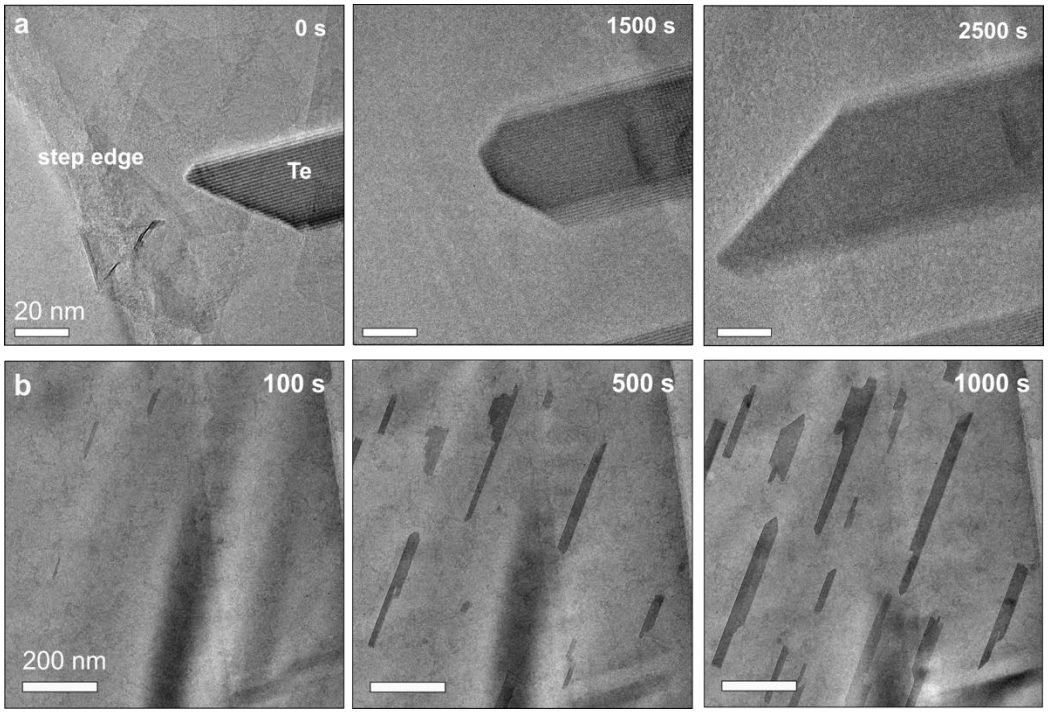


Figure 1. In situ growth kinetics of Te nanoribbons [4]. a, Time series showing changing facets at the tip of a nanoribbon during growth over a substrate step. Note that the field of view changes as the nanoribbon grows. b, Video stills of nanoribbon growth at low-medium flux rate (Tr = 355 °C) and substrate temperature 180 °C.

In this project, we will use in situ Transmission Electron Microscopy (TEM) to observe directly the nucleation, early growth, and interface formation of free-standing Te nanowires on silicon. *In situ* TEM provides unparalleled imaging resolution and allows the capturing of the growth dynamics [*4,5*] and the effect of growth parameters on the growth kinetics in real-time [*Video*]. Using this technique will allow us to understand the growth mechanism and how substrate, temperature, flux, and epitaxial registry control nanowire diameter, growth direction, and chirality. Our goal is to develop a novel platform of aligned, epitaxially grown, chiral-selected Te nanowires on silicon, enabling both structural and electrical characterization. By combining high-purity epitaxial growth, in situ observations, and device fabrication, we aim to establish a reproducible system for spintronic devices exploiting the chiral degree of freedom of Te.

Master 2 internship: The successful applicant will prepare silicon substrates compatible with in situ TEM observation, participate in in-situ growth experiments, and perform advanced image analysis of the resulting nanostructures. During the internship, the student will also interact with Thales (MBE growth of Te) and the LAF group (spintronics applications of Te). The *in situ* experiments will be conducted using the MBE growth method in the NanoMAX TEM. The analysis will be carried out by developing dedicated image-processing algorithms able to extract relevant geometric parameters from each image. The expected result of this work will be to correlate growth conditions with the resulting morphology and define strategies to control the orientation of the nanowires and ultimately control their chirality in view of creating a novel spintronic platform. This internship provides hands-on training in nanomaterials synthesis, electron microscopy, within a multidisciplinary environment bridging growth, characterization, and device applications.

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] J. D. Londoño-Calderón et al., *Robust Atomic- to Meso-Scale Chirality in Ultrathin Tellurium Nanowires Observed by Second Harmonic Generation Circular Dichroism*, Nano Lett. 21, 2021. DOI: 10.1021/acs.nanolett.0c04737

[2] R. Reuven et al., *Anisotropic Circular Dichroism in Aligned Chiral Tellurium Nanorods*, Adv. Optical Mater. 11, 2023. DOI: 10.1002/adom.202203142

[3] Z. Zhang et al., *Oriented Tellurium Nanoribbon Arrays: From Controlled Synthesis to High-Performance Field-Effect Transistors*, ACS Nano 17, 2023. DOI: 10.1021/acsnano.2c11759

[4] K. Reidy, N. R. Ithzak, C. Wei, L. Houben, K. Rechav, P. Miller, P. Knight, F. Panciera, E. Joselevich, F. M. Ross, *In Situ Nucleation and Growth Mechanisms of Tellurium Nanoribbons via van der Waals Epitaxy*, Microsc. Microanal. 31(1), 2025. DOI: 10.1093/mam/ozaf048.907

[5] M. Panciera et al., *Synthesis of Nanostructures in Nanowires Using Sequential Catalyst Reactions*, Nat. Mater. 14, 2015, 820–825. DOI: 10.1038/nmat4329

[6] J. C. Harmand et al., *Atomic Step Flow on a Nanofacet*, Phys. Rev. Lett. 121, 2018, 166101. DOI: 10.1103/PhysRevLett.121.166101