

GNOMES – GaN Nanowires with Oxide Shells: Modification and Enhancement by Surface Engineering



Fig. 1 Image generated with OpenAI's DALL·E

Motivation

The progress of our civilization can be reflected by the development of light sources – from fire, through light bulbs, to efficient light emitting diodes (LEDs) and lasers. In this field, **gallium nitride (GaN)** plays crucial role, since it laid the foundation for highly efficient, ecological, and cheap blue and UV LEDs. Whereas recent progress in **optoelectronics** is driven by **nanotechnology**, GaN in a form of **nanowires** paid scientific attention, as a high-quality, low dimensional quantum system of enhanced luminescence efficiency, in which quantum effects occur. However, the nanowire large surface-to-volume ratio results with high sensitivity to external conditions and large surface states density, which limits nanowire performance. The solution is a **core-shell** system, in which the GaN nanowires are covered with shells. This modifies the properties of the nanowires and enhances their

performance parameters (Fig. 1). However, the interaction between the core and shell remains complex and ambiguous. Thereby, fundamental study is crucial for their analysis, as they contribute to the development of new generation light sources.

Objectives

The GNOMES project focuses on **surface effects** by investigating core-shell structures composed of GaN nanowires covered with wide-bandgap oxide shells. So far, the influence of such shells on GaN nanowires has been barely studied, particularly in the context of amorphous ultra-thin coatings, mixed and multilayer oxide shells, and structures after thermal treatment. This project aims to thoroughly investigate these issues, contributing to advanced surface and defect engineering. It is expected that **the shells will induce changes in the nanowires' structural properties** (e.g. crystal lattice deformation), **optical performance (including luminescence efficiency and environmental stability)**, and **band structure**, with particular emphasis on flat-band effect and surface states redistribution. A key aspect of the research will be investigation of the **optimum shell thickness**, since it has been observed that the most significant enhancement in luminescence efficiency has been reported for thin coatings (Fig. 2). This effect suggests that the influence of different mechanisms can be tuned, providing a great opportunity for in-depth study of surface and interface effects. This makes GNOMES not just a materials-oriented project, but also a **fundamental physics study**, aiming to uncover how surfaces and interfaces control the behaviour and performance of nanostructures.

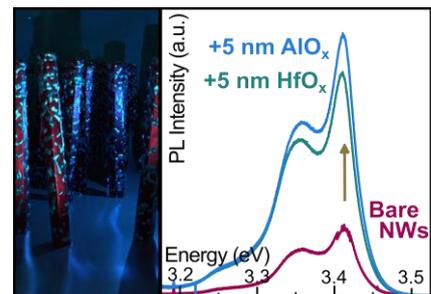


Fig. 2 Increase of core-shell NWs luminescence intensity, Small 20(44) 2401139 (2024)

Research outline

To achieve the project's goal, a systematic and comprehensive study of structures vary in shell material, crystalline phase, thickness, deposition temperature, and precursor type will be carried out using a broad range of material characterisation techniques. **Scanning and Transmission Electron Microscopies** will be employed to image the structure, enabling detailed analysis of the shell morphology, even in the case of ultra-thin coatings just a few nanometres thick. **X-ray diffraction** and **Raman spectroscopy** will give insights into the internal crystalline structure, including phase identification, crystal orientation, and vibrational dynamics. Optical properties, including luminescence efficiency and nanowire sensitivity, will be examined by **photo- and cathodoluminescence** measurements. Low-temperature (10 K) spectra will be used to describe defect states, while surface states will be analysed thanks to **X-ray** and **Ultraviolet Photoelectron Spectroscopies**. Collectively, these methods will deliver a comprehensive description of core-shell interactions, with particular attention to surface and interface effects.

Expected results

Thanks to the GNOMES project, a fundamental study of effects on surface and interface will be performed. Such investigation will provide valuable insights into the non-trivial world of quantum effects, whose presence significantly affects the macroscale performance of opto- and microelectronic devices. As a result, the research will support the fundamental knowledge in physics and surface science, while also setting directions for future developments in optoelectronics, nanotechnology, and material science.