- Axe de GANEX : Axe 7 Matériaux

Titre du sujet : **Analyse chimique nanométrique 3D d'hétérostructures nitrures par sonde atomique tomographique (APT) couplée à la microscopie électronique en transmission (TEM)**

- Nature de la thèse ☐*Simple : GANEX 100%, laboratoire bénéficiaire : INAC*
- Date souhaitée de démarrage : Mars 2015
- Lien avec un projet ANR ou H2020: NanoGANUV
- Lien avec industriels : ALEDIA apporte son soutien au projet
- Sujet développé :

Gallium nitride (GaN) and its alloys with Al and In appear indeed as leading technological materials for a wide range of applications including visible lighting, ultraviolet (UV) emitters, THz optoelectronics or power electronics. As optoelectronic devices push towards higher performance, engineering the quantum confinement at the nano-scale becomes the key for device design. However, such a fine tuning of the physical properties faces one major bottleneck, namely the accurate determination of doping and/or alloy compositions in the few ppm-few % range, at the nanometer-scale and in 3 dimensions (3D).

The present subject will focus on 2 systems:

* Nanowires grown by Molecular Beam Epitaxy (MBE) with InGaN/GaN heterostructures for which the emission wavelength is tuned by the In-content but also depends on local alloy fluctuations. In particular, high In content samples suitable for red emission will be investigated. As the heterostructures usually adopt a core-shell geometry, the composition determination of the active region requires a 3D analysis. Moreover, the spatial repartition of the dopants (Mg or Si) in the nanowires has to be determined.

* $Al_yGa_{1-y}N$ quantum dots (QDs) grown by MBE in $Al_xGa_{1-x}N$ matrices (with $x > y$) for UV emission and in particular the fabrication of LEDs. As above, the emission wavelength depends on the Al-content of the QDs and the local alloy fluctuations. In addition, it depends on the Al content of the matrix, which can be subject to phase separation during the capping of the QDs. Due to the nm scale dimensions of the QDs, the accurate determination of the alloy composition of the complete $Al_yGa_{1-y}N/Al_xGa_{1-x}N$ system is a prerequisite to correlate the QD optical and structural properties. Another challenge concerns the doping of $Al_xGa_{1-x}N$ materials with high Al compositions (in particular for p-type doping), which are required for the development of deep-UV emitters ($\lambda < 300$ nm).

The aim of the thesis is to develop quantitative composition analysis of these two systems reaching the final goal of a precision < 0.5%, and a spatial resolution < 1 nm in 3D. This will be achieved by coupling 2 complementary approaches, namely Atom Probe Tomography (APT) and Transmission Electron Microscopy (TEM). APT is a unique characterisation technique, based on the field effect evaporation of individual atoms of a needle shape sample, allowing the analysis of nano-devices both in terms of morphology and composition in three dimensions at the atomic scale. These measurements will be combined with those made on the same sample by high-resolution electron microscopy (HR-(S)TEM) and Electron Tomography fitted with X-ray spectroscopy (EDX) which will also provide 3D chemical information. The samples will be provided by 2 GANEX partners, namely INAC for the InGaN/GaN nanowires and CRHEA for the AlGaN quantum dots (supported by ANR NanoGaNUV). But the subject is opened to other partners who would have samples requiring such analyses. The experimental work will be performed at the Nanocharacterization Platform (PFNC) located at MINATEC Grenoble with access to last generation electron microscopes (FEI Osiris and TEMIS microscopes equipped with last generation EDX detectors), as well as atom probe tomography equipment and Focussed Ion Beam (FIB) for sample preparation.