AlGaN:Mn - a novel group-III nitride semiconductor for next-generation electronics - ANGEL

Recent technological advancements have highlighted the need for faster and more efficient electronic devices. Consequently, there is increased attention on the emerging field of spintronics and exploring new capabilities of existing materials that are fundamental to electronics. Devices that respond to both weak magnetic and electric fields are leading the way in creating innovative detectors, light-emitting sources, and high-electron-mobility transistors. In this context, spin electronics play a crucial role in pushing forward the development of next-generation electronics. Presently, dilute magnetic semiconductors (DMSs) represent a promising avenue for advancing spintronic functionalities essential for developing electronics. The heterostructures doped with transition metals (TM) based on III-N semiconductors, in particular the AlGaN:Mn, fulfill the requirements of having a wider band gap (3.4 eV – 6.2 eV for AlGaN – adjusted based on the % Al.) compared to GaN (3.4eV) for device technologies. Recently, only several studies have emerged on the growth of AlGaN:Mn using techniques such as metalorganic vapor phase epitaxy (MOVPE), gas source molecular beam epitaxy (GSMBE), and ion implantation. **However, no reports have been made of growing such structures via plasma-assisted molecular beam epitaxy (PA-MBE), marking a pioneering aspect of this project.**

In the project ***"AlGaN:Mn – A Novel III-N Semiconductor for Next-Generation Electronics (ANGEL)***", we aim to develop advanced semiconductor structures based on Mn-diluted $Al_xGa_{1-x}N$, grown using plasma-assisted molecular beam epitaxy (PA-MBE). This technique enables atomically precise control of composition and doping under conditions far from thermodynamic equilibrium, which is essential for tailoring the material's properties at the nanoscale. The project will involve a comprehensive investigation of the structural, optical, electrical, and magnetic characteristics of the developed structures, providing a deep understanding of the fundamental physical mechanisms governing their behavior. By integrating advanced characterization laboratory methods including SEM, TEM, AFM, XPS, UPS, SIMS, and HR-XRD for structural and surface analysis, as well as PL, CER, PR, SQUID magnetometry, and Hall effect measurements for functional properties, and also synchrotron radiation based methods such as XAFS, we will establish direct correlations between growth conditions, atomic- and microstructural features, and macroscopic device relevant parameters.

The expected outcomes include:

- the determination of optimal growth regimes for homogeneous Mn incorporation into AlGaN layers;
- the development of high-quality epitaxial layers with properties suitable for integration into HEMTs and spin-based devices.

Ultimately, this research will contribute to the emergence of a new class of wide-bandgap dilute magnetic semiconductors, with their potential application in energy-efficient, high-performance electronics, and may enable functionalities beyond the limits of conventional charge-based devices. **The ANGEL project represents a crucial step toward realizing of scalable, next-generation spintronic and power electronic technologies.** Through comprehensive investigation, we aim to determine whether it is possible to obtain structurally uniform crystalline AlGaN layers with Mn to a degree equal to, or surpassing, that achieved in the well-studied GaMnN system. A parallel objective is to assess whether the structural, electrical, and magnetic properties of AlGaN:Mn structures can lead to improved device performance parameters, such as enhanced efficiency and prolonged operational stability, particularly in Al-based devices including high-electron-mobility transistors (HEMTs).