

# Engineered GaN Defect Centers for Quantum Emission: Characterization and Photon Extraction Enhancement

Antouman Sallah<sup>1</sup>, Giacometta Mineo<sup>1</sup>, Paweł Mrowiński<sup>3</sup>, Francesco Ruffino<sup>1,2</sup>, Marcin Syperek<sup>3</sup>, Maria G. Grimaldi<sup>1</sup>

1. University of Catania, Department of Physics and Astronomy “E. Majorana”, Cittadella Universitaria, Via Santa Sofia, 64  
95123 - Catania Italy

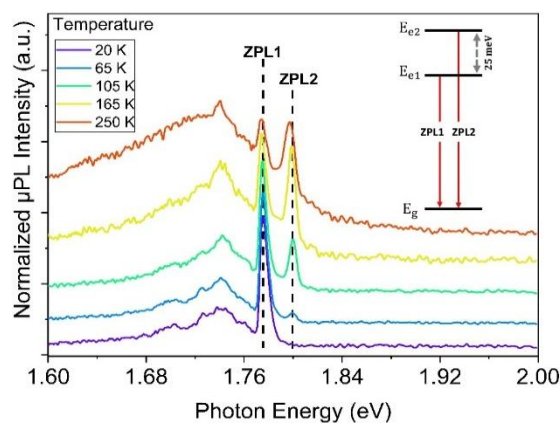
2. CNR-IMM, Università di Catania, Via Santa Sofia 64, 95123 - Catania Italy

3. Wrocław University of Science and Technology, Faculty of Fundamental Problems of Technology, Wybrzeże Wyspiańskiego 27 50-370 - Wrocław Poland

**Abstract:** GaN-based point defects are promising single photon emitters for quantum technologies, but photon extraction and defect formation remain poorly understood. This study addresses both through nanostructuring and ion implantation, characterizing emitters through temperature-resolved PL spectroscopy.

Single photons are a fundamental building block of many emerging quantum technologies, driving exploration of diverse generation platforms. Point defects in wide bandgap semiconductors, particularly color centers in diamond, are among the most studied solid-state single-photon sources [1]. However, diamond as a platform is technologically immature, hence the search for more fabrication-friendly alternatives such as silicon carbide and gallium nitride (GaN). The recent discovery of bright, stable, room-temperature single photon emitters in GaN [2], emitting across a wide spectral range from ultraviolet to infrared opens exciting possibilities for scalable quantum photonic technologies.

Despite advances, important challenges remain. The atomic structure of GaN defects responsible for single-photon emission remains unidentified, and the material's high refractive index severely limits how efficiently photons can be extracted. This study addresses both limitations. First, a cost-effective nanostructuring approach is employed to enhance photon extraction efficiency, yielding a 4.52-fold increase in photoluminescence intensity. Second, localized point defects are introduced through magnesium ion implantation followed by high-temperature annealing under nitrogen overpressure. The resulting emitters are characterized using confocal microscopy with temperature-resolved spectroscopy, revealing two zero-phonon lines: ZPL1 at  $\sim 1.775$  eV and ZPL2 at  $\sim 1.799$  eV, separated by  $\sim 25$  meV with linewidths of  $\sim 7$  meV. The emitters exhibit spectroscopic signatures characteristic of strongly localized deep-level defects, including sharp ZPL emission and well-resolved phonon replicas, consistent with a vacancy-related complex in GaN [3]. Such signatures are analogous to those of well-established color center emitters in diamond, such as the  $\text{SiV}^-$  center.



**Fig. 1.** The emission spectrum evolves from a single ZPL1 at 20 K to two zero-phonon lines as temperature increases, with ZPL2 emerging from a higher excited-state sublevel separated by  $\sim 25$  meV. The inset shows the proposed three-level energy diagram, consistent with a vacancy-related complex in GaN with a split excited-state manifold.

## References

- [1] T. Schröder, S. L. Mouradian, J. Zheng, M. E. Trusheim, M. Walsh, E. H. Chen, L. Li, I. Bayn, and D. Englund, Quantum nanophotonics in diamond, *Optica* **33**, B65 (2016).
- [2] A. M. Berhane, K.-Y. Jeong, Z. Bodrog, S. Fiedler, T. Schröder, N. V. Triviño, T. Palacios, A. Gali, M. Toth, and D. Englund, Bright room-temperature single-photon emission from defects in gallium nitride, *Advanced Materials* **29**, 1605092 (2017).
- [3] C. G. Van de Walle and J. Neugebauer, First-principles calculations for defects and impurities: Applications to III-nitrides, *Journal of Applied Physics* **95**, 3851 (2004).