Polariton lifetime measurements in a GaN-based waveguide through far field time-resolved micro-photoluminescence

L. Méchin [1,*], F. Médard [1], J. Leymarie[1], S. Bouchoule[2], B. Alloing[3], J. Zuñiga-Pérez[3,4], P. Disseix[1],

[1]Université Clermont Auvergne, Clermont Auvergne INP, CNRS, Institut Pascal, F-63000 Clermont-Ferrand, France
[2]Centre de Nanosciences et de Nanotechnologies, CNRS, Université Paris-Saclay, F-91120 Palaiseau, France
[3]Université Côte d'Azur, CNRS, CRHEA, rue Bernard Gregory, Sophia Antipolis, F-06560 Valbonne, France
[4]Majulab, International Research Laboratory IRL 3654, CNRS, Université Côte d'Azur, Sorbonne Université, National University of Singapore, Nanyang Technological University, Singapore 117543, Singapore

Exciton-polaritons, i.e. hybrid light-matter quasiparticles arising from the strong coupling between electromagnetic modes and excitonic resonances [1], have garnered significant interest for their unique bosonic properties. While planar microcavities [2] enable in-depth studies on polariton condensation, superfluidity, and topological effects, the use of Bragg mirrors poses challenges for optoelectronic applications. An alternative is to use waveguide geometry [3], offering strong light-matter interaction, efficient electrical injection, and high group velocities suitable for ultrafast devices. Among potential materials, GaN stand out due to its high exciton binding energy and well-established fabrication processes, making it ideal for room-temperature operation. Developing polariton-based devices requires an in-depth knowledge of gain mechanisms and particularly the relaxation of polaritons along the dispersion curve.

In this work, we propose a novel experimental technique to directly measure the lifetime of polaritons in a GaN-based polaritonic waveguide. Using a Fourier imaging setup combined with spatial filtering, we temporally analyze the emission at each propagation constant of the guided polaritonic mode by directing it to the entrance slit of a streak camera. Time-resolved photoluminescence (TRPL) measurements were performed along the lower polariton dispersion branch at 40 K, and the polariton decay was fitted using a two-level transfer model. Within the coupled oscillators framework, we determine a Rabi splitting of Ω = 80 meV and a photon lifetime in the waveguide of $\tau_\gamma = 3 \pm 1$ ps, corresponding to a record Q-factor of 16 000. TRPL measurements of excitonic luminescence allow us to determine the lifetime of the excitonic reservoir, which contributes to polariton formation and depends on the built-in electric field in the active layer [4]. Finally, low-temperature measurements (5.3 K) reveal secondary feeding mechanisms for the guided polaritonic mode: (i) photon recycling from the AlGaN cladding layer or (ii) resonant injection of photons from transitions below the band gap [5]. These findings offer key insights into polariton dynamics and pave the way for the development of low-power and high-speed polaritonic devices.

Acknowledgments

The authors acknowledge fundings from the French National Research Agency (ANR-24-CE24-0021-03, ANR-11-LABX-0014) and EU under program PolArt(grant agreement No. 101130304). We also thank RENATECH, the French national network of large micro-nanofabrication facilities.

References

[1] J. Hopfield, *Phys. Rev.* **112**, 1555 (1958).

[2] C. Weisbuch, M. Nishioka, A. Ishikawa, and Y. Arakawa, *Phys. Rev. Lett.* **69**, 3314 (1992).

[3] P. M. Walker, L. Tinkler, M. Durska, D. M. Whittaker, I. J. Luxmoore, B. Royall, D. N. Krizhanovskii, M. S. Skolnick, I. Farrer, and D. A. Ritchie, *Applied Physics Letters* **102**, 012109 (2013).

[4] L. Méchin, F. Médard, J. Leymarie, S. Bouchoule, B. Alloing, J. Zuñiga-Pérez, and P. Disseix, *arXiv:2501.07164*.

[5] L. Méchin, F. Médard, J. Leymarie, S. Bouchoule, J.-Y. Duboz, B. Alloing, J. Zuñiga-Pérez, and P. Disseix, *Phys. Rev. B* **109**, 125401 (2024).

*E-mail: loic.mechin@uca.fr