Impact of Internal Electric Field on Polaritonic Lifetime in a GaN-Based Waveguide

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For decades, it has been proposed to use the strong coupling regime, i.e. a reversible exchange of energy between the electromagnetic field (confined photons) and the material dipoles (excitons), to lower the threshold of semiconductor lasers. This scheme has been exploited for twenty years in vertical microcavities and, more recently, it has been adapted to planar waveguides. Put forward by Walker *et al.* [1], polaritonic waveguides offer the advantage of confining the electromagnetic field within the guiding layer through total internal reflections, lifting the need of highly-demanding distributed Bragg reflectors. Wide-bandgap semiconductors such as GaN are of particular interest for the development of devices due to (i) robust excitons stable up to room temperature and (ii) well mastered technological processes.

In this work we present a complete study by optical spectroscopy of a nitride-based waveguide grown by metal-organic vapor phase epitaxy (MOVPE) on c-plane sapphire substrate. This monomode waveguide consists of a 150 nm thick GaN layer grown on top of a 1.5 µm thick $Al_{0.08}Ga_{0.92}N$ cladding. Due to their polar nature, nitride-based heterostructures are subject to strong internal electric fields whose amplitude exceeds a hundreds of $kV{\cdot}cm^{-1}$, leading to the formation of two-dimensional hole and electron gases at the interfaces [2].

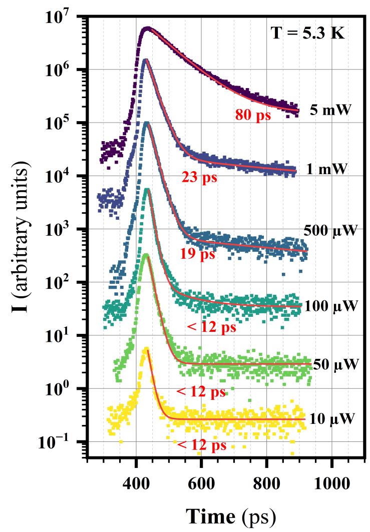

Fig. 1. Exciton lifetime evolution as function of the average excitation power. The excitation is achieved by a tripled Ti:sapphire laser at 266 nm (150 fs pulse duration - 76 MHz repetition rate).

This work elucidates the impact of internal electric fields within the different layers of the heterostructure on the guided polaritons. Time-resolved photoluminescence (TRPL) measurements reveal that the internal electric field significantly reduces the lifetime of the excitons from the reservoir in the GaN guiding layer (<12 ps). The progressive evolution of excitation density across the material demonstrates a screening of the electric field by optically injected free carriers and results in an increase of the exciton lifetime towards the bulk value (90 ps) measured in a thick layer without electric field [2]. To determine the impact of electric field on guided polaritons as a function of optically injected carriers density, we have measured their dispersion using far-field spectroscopy on a SiO_2 diffraction grating, that coupled the guided modes out of the structure. We compare these results with direct measurements of the polariton lifetime obtained by imaging each wave-vector on the entrance slit of the streak-camera.

Our work highlights the necessity to consider the influence of internal electric fields on the polaritonic properties of nitride-based waveguides. As demonstrated, the lifetime of excitons, and thus polaritons, is strongly affected by the electric field. It will therefore be possible to use these properties to improve the efficiency of carrier injection and thus modify the laser threshold of such structures.

References

[1] P. M. Walker et al., Ultra-Low-Power Hybrid Light–Matter Solitons, Nat Commun 6, 8317 (2015).

[2] L. Méchin et al., Experimental Demonstration of a Two-Dimensional Hole Gas in a GaN/AlGaN/GaN Based Heterostructure by Optical Spectroscopy, Phys. Rev. B 109, 125401 (2024).