# Engineering quantum many-body interactions with strong light-matter coupling

**A. Rahmani [1,*], D. Ko [1], M. Dems[2], M. Matuszewski[1,3],**

[1]Institute of Physics Polish Academy of Sciences, Al. Lotników 32/46, 02-668 Warsaw, Poland
[2]Institute of Physics, Technical University of Łódź, ul. Wólczańska 219, 93-005 Łódź, Poland
[3]Centre for Theoretical Physics, Polish Academy of Sciences, al. Lotników 32/46, 02-668 Warszawa, Poland

We propose an effective formalism for manipulating nonlinearity among polaritons. By patterning the active layers within the cavity, we enhance the polariton-polariton interaction strength by approximately forty-fold while maintaining the strong light-matter coupling regime. Starting from Maxwell's equations, we first derive a quantized representation of electromagnetic fields in confined structures that break translational symmetry. Specifically, we solve Maxwell's equations for microcavities incorporating transition metal dichalcogenides (TMDs) and GaAs-based semiconductors. This framework inherently accounts for decay effects, where the environment is treated using open system theory, modeling dielectrics as coupled to a continuum of oscillatory modes. We then formulate the Hamiltonian of a lossy confined electromagnetic field using the second quantization formalism, leading to a master equation that captures the system's electromagnetic response. Additionally, we design a semiconductor heterostructure that hosts two polariton modes, incorporating cross-Kerr nonlinearity alongside Kerr nonlinearity to enrich the system's nonlinear features [1].

Our results show a promising method, based on available experimental technology, to achieve the quantum regime of polaritons [2], enabling realistic polaritonic applications such as quantum simulators [3].

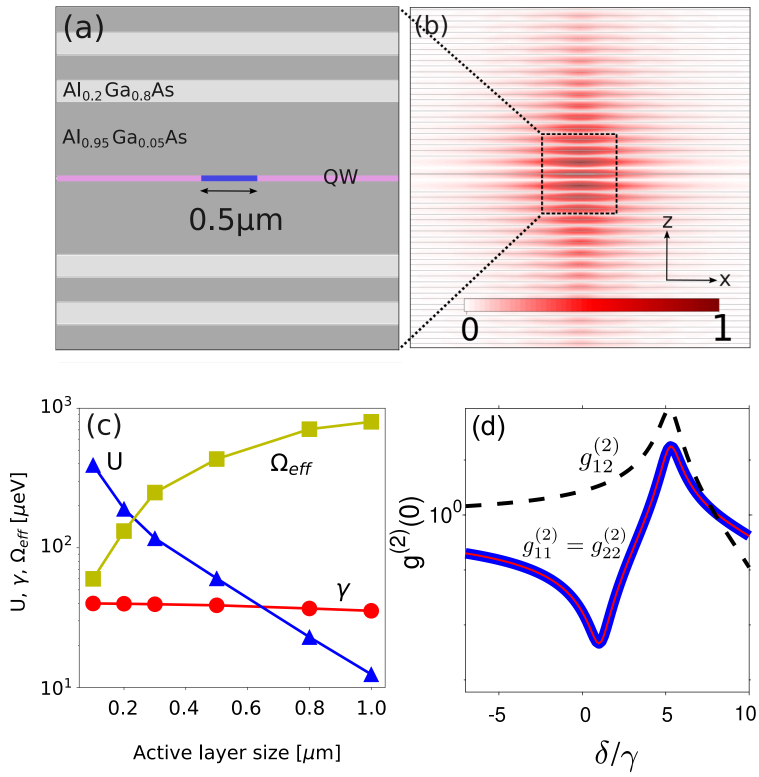


Figure 1: (a): Example of patterning the active layer (shown in blue) inside a GaAs-based semiconductor microcavity. (b) Electric field intensity distribution inside the cavity. (c): Variation of interaction constant (U), coupling constant ($\Omega_{\text{eff}}$), and decay $\gamma$ of polaritons in terms of active layer size. (d): Example of the zero-delay second-order correlation function as a function of pumping detuning. The dashed line shows the cross-second-order correlation in the two-mode polariton regime.

## References

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*E-mail: rahmani@ifpan.edu.pl