Quantum computation of the dynamics of the Jaynes-Cummings Hamiltonian for nanophotonics

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The strong coupling of excitons in quantum emitters with the modes of optical resonators leads to the emergence of hybrid excitations with novel properties that can be identified by Rabi oscillations in time domain. Usually, the realization of this effect requires cryogenic temperatures. However, this constraint can be overcome by confining the optical energy to an extremely small volume through metallic nanoresonators that support plasmonic resonances induced by the collective oscillations of the free electrons of the metal. A sketch of a such a configuration is shown in Figure 1.

We first describe the interest of the coupling between plasmonic nanoresonators and quantum emitters for molecular characterization and for the design of sources of quantum light. The physics of these systems can be modelled using the Jaynes-Cummings Hamiltonian for a single plasmonic mode coupled to a single quantum emitter treated as a two-level system.

We then implement the Jaynes-Cumming Hamiltonian in an IBM quantum computer after qubitization of the bosonic plasmonic excitation [1,2], and obtain the resulting time evolution of states population(Figure 2). We describe how, under adequate conditions, there is no trotterization error [3]. This work thus makes it possible to assess the possibilities of quantum computing to treat these systems, as a first step towards the study of more complex configurations involving many quantum emitters, for example, where the size of the Hilbert space makes classical calculations challenging.

References

[1] R. D. Somma arXiv: quant-ph/0512209 (2005).
[2] Xin-Yu Huang et al., arXiv:2105.12563, 2021
[3] Naomichi Hatano and Masuo Suzuki, arXiv:math-ph/0506007 (2005)

Figures

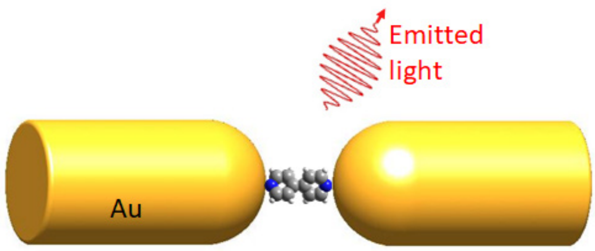

Figure 1: Sketch of a typical emitter-resonator system, where a quantum emitter (here, a molecule) is coupled with an optical nanoresonator.

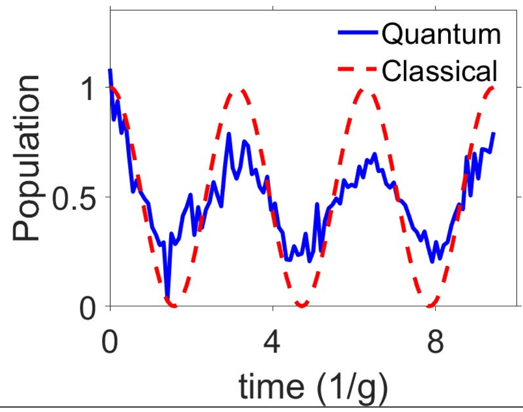

Figure 2: Population of a quantum emitter coupled to a plasmonic nanoresonator, obtained using classical (dashed red line) and quantum (solid blue line) simulations. The results show clear Rabi Oscillations in both cases. The time is given in units of 1/g, where g is the nanoresonator-emitter coupling strength.