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A new photonic crystal platform for interfacing slow light and trapped cold atoms

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Trapping cold neutral atoms in close proximity to nanostructures has raised a large interest in recent years, pushing the frontiers of cavity-QED and boosting the emergence of the waveguide-QED field of research. Such platforms interfacing trapped cold atoms and guided light in nanoscale waveguides are a promising route to achieve a regime of strong coupling between light and atoms, and implement non linear quantum optics protocols [1]. In this context, we propose to interface ^{87}Rb atoms with a GaInP waveguide based on a 2D photonic crystal waveguide (PCW) [2]. The periodic arrangement of holes allows to shape the dispersion relation and engineer slow-modes, whose interaction with quantum emitters would be enhanced, allowing for strong coupling even in single pass. At the same time, guided modes are used to form dipole traps for the atoms, a crucial requirement for achieving strong coupling. The asymmetry of the proposed waveguide offers more control on the shape of the dispersion bands as well as an increased optical access, critical to bring the atoms close to the surface.

The coupling of the atoms to the waveguide can be characterized by the Purcell factor, which relates the decay rate of the atoms into the guided mode to the one into free space. Dispersion engineering by tuning the geometrical parameters of the PCW via systematic optimization, can lead to a high constant group index $n_g \sim 30$ over a range of 10 nm, centered around $\lambda_{Rb}^{D2} = 780$ nm. This constant index over a large range makes the design more robust to fabrication imperfections. With this robust design, at realistic distances of ~ 100 nm from the waveguide surface, 3D FDTD calculations reveal that Purcell factors of 2 can be expected (meaning $\frac{\Gamma_{1D}}{\Gamma_{TOT}} \geq 70\%$).

We introduce a stable and compensated trapping scheme around our PCW for ^{87}Rb atoms based on an evanescent two-color dipole trap formed by fast guided modes, with powers under the milliwatt. This configuration was computed thanks to \texttt{nanotrappy} [3], a Python package developed by our group, to design, calculate and optimize dipole traps around nanoscale waveguides, making the search process faster and more systematic.
Experimental realization of the cold atoms system is ongoing and promising first structures have been fabricated.

[1] D. E. Chang, et al., *Rev. Mod. Phys.*, **90**, 031002 (2018)
[2] X. Zang, et al., *Phys. Rev. Appl.*, **5**, 024003 (2016)
[3] J. Berroir*, A. Bouscal*, et al., *Phys. Rev. Res.*, **4**, 013079 (2022)

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