Quantum nonlinear optics based on 2D Rydberg atom arrays

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In this project [1], we explore the combination of sub-wavelength, two-dimensional atomic arrays, and Rydberg physics as a powerful platform to realize strong, coherent interactions between individual photons with high fidelity.

In particular, the spatial ordering of the atoms guarantees efficient atom-light interactions without the possibility of scattering light into unwanted directions, for example, allowing the array to act as a perfect mirror for individual photons (Fig. 1a). In turn, Rydberg interactions enable single photons to alter the optical response of the array within a potentially large blockade radius R_b, which can effectively punch a large "hole" for subsequent photons (Fig. 1b). Such a system enables a coherent photon-photon gate or switch, with an error scaling that is significantly better than the best-known scaling in a disordered ensemble (Fig. 1c, d).

References

[1] D. Goncalves, M. Moreno-Cardoner, and D. E. Chang, **Phys. Rev. Lett. 127**, 263602 (2021).

Figures

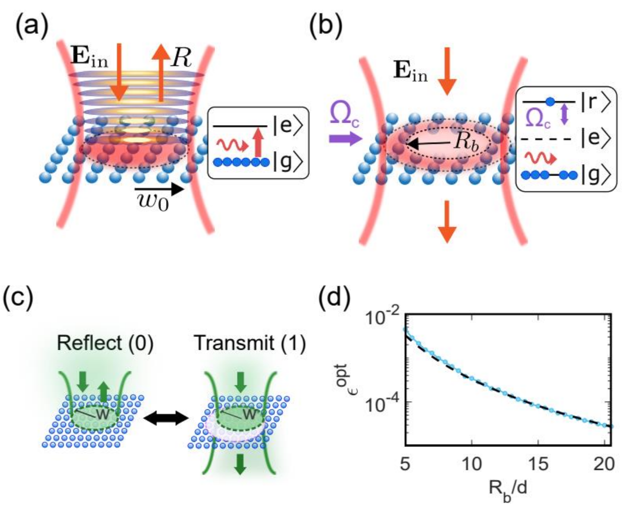

Figure 1: Illustration of a sub-wavelength 2D array of two-level atoms ($|g\rangle$,$|e_i\rangle$) reflecting a resonant input gaussian beam with beam waist w_0. (b) Next, we consider a Rydberg state $|r_i\rangle$ coupled to the $|e_i\rangle$ levels by means of a control field Ω_c. Storing a Rydberg excitation results in an energy shift that breaks the mirror resonance condition within the blockaded region of radius R_b. (c) Combining the phenomena from (a-b) we build a single-photon switch, where the transmission/reflection of a signal photon is conditioned to the storage/retrieval of a gate photon. (d) Switch error ϵ^{opt} (photon loss) as a function of R_b after optimizing the system's parameters. The scaling ($\epsilon^{opt} \sim R_b^{-4}$) and the predicted performance outperforms any current ensemble-based protocols.