Minimalistic quantum devices build of dipole-coupled nanoscopic arrays of quantum emitters

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ABSTRACT

Subwavelength arrays of quantum emitters feature unique and largely design-able nonlinear optical properties. As a generic example we study a sub-wavelength sized ring of identical dipoles with an extra identical absorbing emitter at the center. For a 9-ring one finds the most efficient antenna configuration to direct single incoming photons to the center without re-emission. Interestingly, for very tiny structures sizes below a tenth of a wavelength, a full quantum description predicts an even larger absorption enhancement than a mean field model using a classical dipole approximation. We identify the origin of the enhancement in the appearance of a collective dark state with dominant center occupation. By special design of the center absorber one thus can harness the same efficiency enhancement also at different wavelengths and for other geometric structures. On the one hand this idea could be the basis of a new generation of highly efficient and selective nano antennas, while on the other hand, it could be an important piece towards understanding the surprising efficiency of natural light harvesting molecules. Adding gain via active dipoles in such nano ring systems allows to design minimalist laser like classical light sources. In the nonlinear operating regime at stronger pump fields these systems transform to non-classical light sources with tailor-able spatio-temporal emission upon coherent illumination.

Keywords: quantum emitters, nano-photonics , dipole-dipole coupling

1. INTRODUCTION

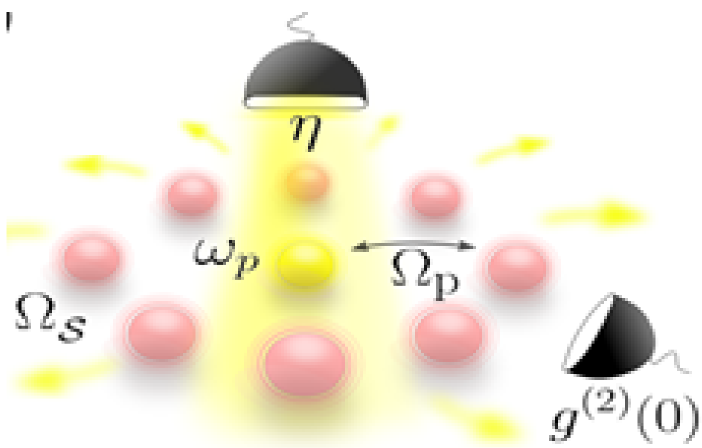

Figure 1. Exemplaric scheme of a single photon nano antenna build of a circular dipole array with central absorber

Collective radiation effects such as sub-radiance and super-radiance arise in ordered structures of quantum emitters at sub wavelength distance. Such vaccuum-mediated dipole-dipole interactions in free space are nowadays attracting renewed interest. This is partially triggered by the fact that recently it has become possible to realize almost any spatial arrangements at will using individually trapped atoms in optical tweezers. Moreover,

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such sub-wavelength structures can also be implemented using superconducting qubits in the microwave waveguides or using structured growing of quantum dots. These systems can be regarded as novel quantum optics platforms that enable an enhanced atom-light coupling, which can outperform previously established bounds in quantum protocols including single photon storage, spectroscopy, or opto-mechanics. Moreover, it represents a new playground for exploring fundamental physics involving quantum many body states of light and matter.

An array of closely spaced, dipole coupled quantum emitters exhibits collective energy shifts as well as super- and sub-radiance with characteristic tailor-able spatial radiation patterns. Symmetric configurations as straight lines, 2D regular lattice structures or ring shaped regular polygons have particularly special properties.[1] As striking example we show a single photon antenna build from a ring of dipoles with central absorber. For the fully symmetric case a 9-ring exhibits optimal performance. The setup is depicted in Fig.1.[2–4] The corresponding absorption cross section as function of ring size and center loss rate is depicted in Fig.2. On clearly sees that a 9-ring has superior properties in particular for very small sample sizes.

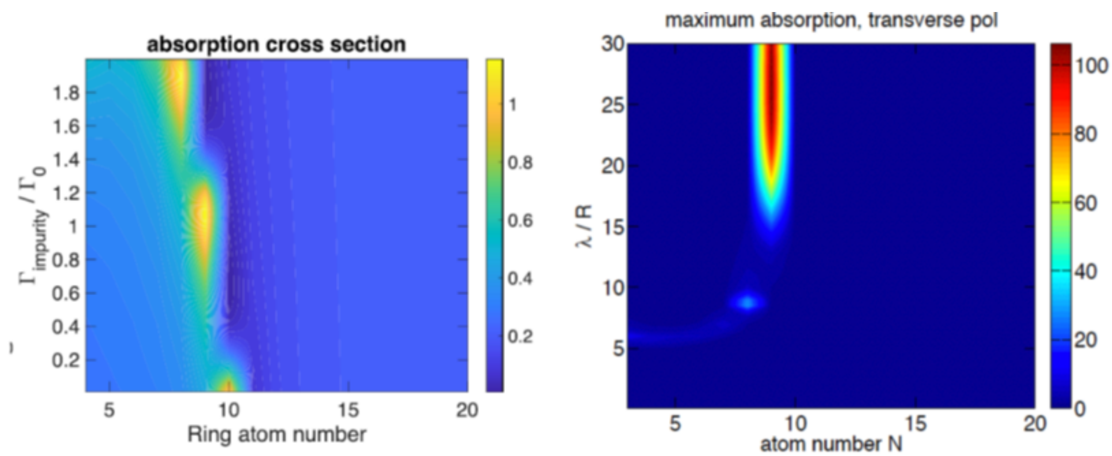

Figure 2. (left) Absorption efficiency as function of ring atom number and energy extraction ratio and (right) as function of ring size and emitter number.

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