Engineering quantum states of light with optical nanoantennas

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Quantum emitters, such as atoms, molecules, NV-centers in diamonds, etc., can act as sources of nonclassical light. A simplest example of such source is the single-photon emission from a pumped two-level quantum system. Quantum dots (QDs) are especially promising examples of such emitters, as their energy and symmetry structure can potentially be tailored, so that the emitted light might be characterized by desired quantum statistics, spectrum, polarization, or even high degree of entanglement [1].

Naturally, harvesting nonclassical light from bare quantum emitters is rather inefficient, since their coupling to electromagnetic fields is small due to the radical mismatch of the size of the emitter and the wavelength of light. This disproportion is typically overcome with the use of dielectric cavities, that confine electromagnetic fields into small spatial domains. There is, however, a natural diffraction limit to such confinement in classical resonators, determined eventually by the field wavelength. *This limit can be exceeded if plasmonic nanoantennas (NAs) are exploited instead of traditional dielectric cavities.*

Metallic or metallo-dielectric NAs are able to efficiently convert between propagating and localized modes of electromagnetic fields. Their capability of field confinement to subwavelength regions of space, and the corresponding field enhancement by several orders of magnitude, makes them *perfect candidates to tailor light-matter interactions*.

The spectrally broad modes supported by high-efficiency NAs give rise to huge Purcell enhancement factors of light emission by the adjacent QDs. For example, Purcell factors of 3 orders of magnitude have been observed in Ru-dye molecules situated between a gold film and a silver nanocube [2]. Naturally, *the effect of intensified emission applies also to nonclassical states of emitted light*. Moreover, the directivity of the source may be boosted by supplementing the plasmonic structure with dielectric components [3]. Therefore, *such designs promise applications for directional and bright nonclassical-light emitters* [4].

The efficiency of plasmonic NAs is, however, limited, since energy dissipation is intrinsically linked to the very nature of plasmonic resonances. Therefore, *using plasmonic NAs unavoidably leads to a trade-off between brightness of the light source and the quantum properties of emitted light*, defined in terms of fidelity or correlation functions [4].

In our work, the optical properties of NAs, such as their scattering and absorption spectra, are obtained by numerically solving the Maxwell's equations in the frequency domain. In practice, the considered NAs can be well described with an approximation of a single or a limited number of quasi-normal modes, which in general may be coupled to form Fano-shaped resonances. The properties of the supported modes can be accounted for by a small number of fitting parameters, corresponding to their central frequency, radiative and nonradiative loss rates, coupling strengths between the modes as well as their interaction strength to QDs located at their vicinity [5]. This means that a cQED-like treatment, with Jaynes-Cummings-type Hamiltonian and suitable Lindblad terms to account for incoherent processes, can be applied to describe the dynamics of a system consisting of the light modes supported by the NA and adjacent quantum emitters [6].

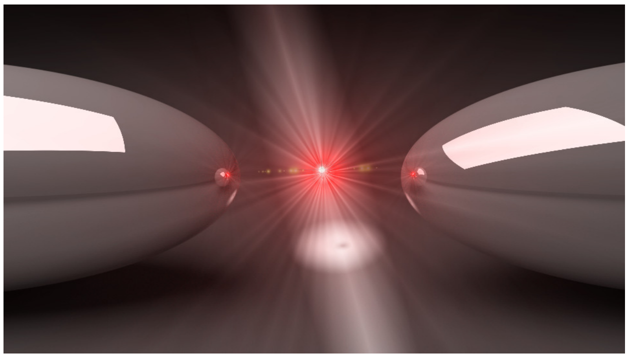

FIG. 1. An artistic vision of a quantum dot coupled to an optical nanoantenna. The system may act as a source of nonclassical light.

Equipped with such methodology, we will propose and examine specific designs of QD + NA systems that support the emission of nonclassical states of light such as single photons on demand [4, 8], polarization-entangled photon pairs [1] or N-photon bundles [7, 8]. We will discuss the performance of such sources as a function of geometrical and spectral parameters of NAs and contrast it with the quality of the emitted light.

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