Monolithic directional optical antennas for funneling photons to single emitters

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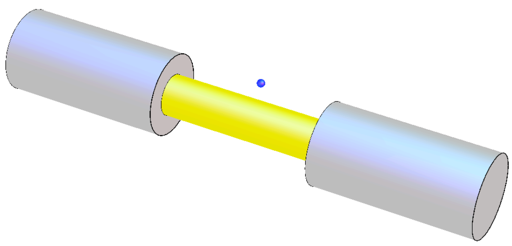
An emerging strategy for achieving efficient coupling of single emitters with photons relies on optical antennas. Here, we propose a class of metal nanostructures that feature directionality, strong field enhancement, and low losses for applications in quantum photonics and quantum nano-optics.

Introduction

Coupling single photons with single quantum emitters has become central to nanophotonics, for the implementation of integrated quantum networks and computing, but also for improving classical ways of processing information such as optical switching [1]. Progress in nano optics has shown that optical antennas [2] and plasmonic waveguides [3] can lead to large coupling efficiencies with broadband operation and better miniaturization in comparison to micro-resonators. However, optical antennas suffer from dipolar radiation patterns, which require high numerical-aperture optics for achieving strong couplings, and directional antenna arrays imply accurate handling of each individual element at the nanoscale [4]. On the other hand, practical exploitations of plasmonic waveguides need a rapid and effective conversion of surface plasmon-polaritons (SPPs) into photons, especially in the near infrared spectral range. Here, we propose a class of optical antennas that combines the high directionality of plasmonic waveguides with the performances and simplicity of dipole antennas.

Results

The figure below illustrates the concept of integrated monolithic directional antennas, where a finite metal nanostructure acts as an efficient light-matter interface between a nearby quantum emitter and photons, as well as a mode converter for coupling to a lossless waveguide. As an illustrative example, we consider metal nanowires butt-coupled to a dielectric fiber. Under appropriated conditions, we show that more than 95% of the incident guided photons are converted into SPPs and vice versa. The mechanism that boosts the coupling efficiency relies on the formation of a weak resonance at the nanowire-fiber interface, which entails a relationship between the operating wavelength and the nanowire and fiber radii. When we replace the nanowire with a truncated metal cone, SPPs nanofocus towards the cone tip to yield intensity enhancements of more than three orders of magnitude and, when propagating backward, collection efficiencies above 70% in the near infrared spectral range [5,6].



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