

control light emission

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PhD Thesis Defense ALBERTO GONZALEZ CURTO 'Optical Antennas Control Light Emission'

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Nanophotonics

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The emission of light is at the heart of both fundamental science and technological applications. At its origin lie electronic transitions in nanoscale materials such as molecules, atoms and semiconductors. The interaction of light with such single quantum emitters is inefficient because of their point-like character. Efficient interfaces between light and nanoscale matter are therefore necessary.

Inspired by the effective communication between small electronic circuits enabled by radio-frequency antenna technology, an emitter can be addressed efficiently with a nanoantenna, an optical element that converts localized energy into propagating radiation.

The control of light emission with such optical antennas is the topic of this Thesis. By coupling an emitter to a metal antenna, the emission properties are determined by the antenna mode in direction, transition rates, polarization, and spectrum. In Chapter 1, we set out the basic concepts of optical antenna theory.

To couple an emitter to an antenna, it must be within its near field. In Chapter 2, we introduce a nanofabrication method to place quantum dots on metal nanostructures with high spatial accuracy. The resulting emitter-antenna systems are imaged by confocal microscopy and their angular radiation patterns directly recorded. This combination of experimental methods allows us to study any optical antenna.

A metal wire is the canonical antenna design and the basis to understand and construct other optical antennas. Through selective coupling of a quantum dot to the resonant modes of a nanowire, we demonstrate in Chapter 3 that the emission of a dipolar source can be converted controllably into higher multipolar radiation. We describe the antenna as a standing-wave resonator for plasmons and reproduce its emission with a multipolar expansion.

An aperture in a metal film can be regarded as the complementary structure of a wire. In Chapter 4, we address the emission of light through a rectangular nanoaperture as an antenna problem. We demonstrate, explicitly, that resonant nanoslot antennas display a magnetic dipole response. Such antennas offer an efficient interface between emitters and surface plasmons.

The excitation or detection of a dipolar emitter from the far field involves large solid angles. To address quantum emitters efficiently, a low divergence of their radiation patterns is needed. To this end, in Chapter 5 we develop and realize unidirectional optical antennas. We show how the emission of a quantum emitter is directed by multi-element Yagi-Uda and log-periodic optical antennas and demonstrate directional operation of a single-element

design based on a split-ring resonator.

Light emission usually occurs through electric dipole transitions because multipolar emission rates are orders of magnitude slower. In some materials, however, multipolar optical transitions do occur. In Chapter 6, we assess through simulations the feasibility of enhancing magnetic dipole and electric quadrupole transitions with several realistic nanoantenna designs.

The results in this Thesis demonstrate the potential of optical antennas as elements to control light on the nanoscale, based on radio and microwave antenna engineering. Within this powerful paradigm, the interaction of light with nanoscale matter can be tailored with complete flexibility. Such a degree of control over light emission and absorption may have a practical impact in spectroscopy, sensing, display technologies, lighting, photovoltaics, and general optical and optoelectronic devices.

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