PhD THESIS DEFENSE: Contributions to nanophotonics: linear, nonlinear and quantum phenomena

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Nanophotonics can be defined as the science and technology studying the control optical fields at the nanoscale and their interaction with matter. In order to spatially control such fields we would need structures with characteristic dimensions of the order of the wavelength, bringing us to the nanoscale.
A way to control optical fields at this scale is the use of nanoantennas, optical equivalent of radio-antennas. They provide efficient interfaces between near-fields generated by light sources and radiative channels. After a brief Introduction, Chapter 2 describes interaction between single photon emitters and nanoantennas. We start the chapter introducing a method to numerically simulate the interaction. A key concept to solving Maxwell equations is that of the Green function. I show how this function relates to the emission rate of optical

emitters in a nanophotonic environment. I then describe an our efforts to build a lifetime-imaging near-field scanning optical microscope. Using this rig we are able to measure changes changes in the emission rate of single emitters that interact with resonant optical antennas.

A complementary way to control optical field in the nanoscale is using dielectric confinement. Chapter 3 introduces hybrid structures combining nanoantennas and dielectric waveguides. I generalize the Green function formalism introduced in Chapter 2, and show how this is related to the energy transfer rate between a donor and an acceptor. I use this numerical method to calculate the energy transfer rate in a hybrid structure. An increase of orders of magnitude is found at distances of the order of the wavelengths of the transferred photons. This chapter finishes by discussing the role that the local density of optical states has on the energy transfer efficiency.

Nanoantennas increase near-field by orders of magnitude. In these conditions, nonlinear optical effects start to play a role. Chapter 4 is devoted to these nonlinear interactions mediated by nanoantennas. I explore nonlinear interactions in resonant nanoantennas, in particular SHG. First I introduce a method to numerically compute the contributions to SHG generated by the metal in nanoantennas. Both surface and bulk contributions to SHG are considered. I use the numerical method to show that narrowings within the antenna shape are sources of increased SHG. The increase in SHG is attributed to increase of the local field gradients, that increase to the bulk contribution to SHG. We numerically validate our results by performing SHG measurements at the single resonant antenna level.

Optical fields are functions of space, but also of time. The development of broadband femtosecond lasers and pulse shaping techniques allows control of optical field down to the femtosecond timescale. Chapter 5 explores the control of optical fields in time. Using phase shaping methods we optimize the two-photon absorption process in single QDs. I introduce a new optimization algorithm, that allows us to perform the optimization using as feedback signal the luminesce from single QDs. We then compare our results with standard phase shaping techniques.

Based on their success to effectively control all kinds of optical fields, plasmon supporting nanoantennas are being actively researched in the field of quantum optics. In Chapter 6 I describe a quantum eraser experiment mediated by structures supporting surface plasmon resonances. I first explain the details and subtleties of a quantum eraser experiment. I then detail our efforts to reproduce previously reported results about how to fabricate elliptical bullseye antennas behaving as quarter waveplates. Quarter waveplates are a required part for the quantum eraser effect to take place. An additional key component of our experiment is a bright, state-of-the-art entangle polarization entangle photon source that is described at length. We then perform a quantum eraser experiment mediated by plasmons.

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