

## Abstract

This Thesis is focused on the development and characterization of self-assembled hyperbolic metamaterials-based photonic devices for enhanced single-photon sources.

In the last decades, different kinds of single-photons sources (SPSs) have been deeply studied for the development of photonic devices in fields such as quantum computing, quantum communication and metrology. Unfortunately, most of the SPSs are characterized by drawbacks that limit their applications. For example, a solid-state SPS such as Nitrogen-Vacancy (NV) in diamond lattice is featured by low emission rate and a broadband emission. To overcome such limitations, we propose the exploitation of self-assembled hyperbolic metamaterials.

Hyperbolic metamaterials (HMMs) are artificial material designed to provide optical properties that cannot be found in natural materials. They are usually composed of two alternating materials: a metal and a dielectric. HMMs are characterized by periodic structures with typical periodicity dimensions ( $\Delta$ ) that are much smaller than the incident wavelength of interest. In this work, the typical dimensions are at the nanoscale since the incident wavelengths of interest are in the visible range, i.e.  $\Delta \sim 40$  nm. The nanostructured materials introduce an anisotropy in the permittivity tensor that leads to a hyperbolic isofrequency surface. The exotic isofrequency surface shape enables two interesting optical properties: the directional emission and the increase of the available optical states, and consequently the enhancement of the spontaneous emission. Hence, properties allow to overcome some of the typical limitations of solid-state SPS.

In order to fabricate the HMMs, self-assembling block copolymers (BCPs) have been used. BCPs are composed of two or more immiscible homopolymer chains linked by a covalent bond. The most interesting characteristic of BCPs is represented by their capability to organize themselves in periodic nanostructures. The self-assembly can be induced by providing thermal energy by means of an

annealing process. By exploiting BCP self-assembly different final morphologies can be obtained by varying the volume fraction: gyroids, cylinders, and spheres. In this Thesis, we focused our attention on the fabrication of lamellae perpendicular to the substrate. Then, the polymeric lamellar nanostructure has been used to obtain a hyperbolic metasurface composed of lamellae made of gold and air.

To investigate the proposed hyperbolic metasurface, the sustained modes have been calculated through modal analysis exploiting quasi-normal modes formalism. In addition, simulations have been performed by means of Finite Element Method software Comsol Multiphysics 5.2 to study the optical response of the hyperbolic metasurface, in terms of emission enhancement, when coupled to a dipole as photon emitter. The obtained results showed a good agreement with the experimental optical characterization for what concerns the wavelength region where the enhancement occurs. The measurements have been performed analyzing the photoluminescence emission of NVs in nanodiamonds dispersed on the fabricated hyperbolic metasurfaces.

In addition, in this dissertation we discuss the fabrication of a tool for the estimation and characterization of the increased number of available optical states: a diamond-based nano-probe for optical near-field characterization. The proposed probe is composed of an Atomic Force Microscopy (AFM) tip with an emitting nanodiamond on top of it.

Finally, we present further techniques for the fabrication and optical characterizations of self-assembled hyperbolic metamaterials that will be used to enhance single-photon sources' emission.