ICFO

PhD Thesis Defense ESTEBAN BERMUDEZ 'Hybrid Photonic-Plasmonic Devices with Single Nanoscale Light Sources'

ESTEBAN BERMUDEZ

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Monday July 17, 11:00. ICFO Auditorium

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Plasmon Nano-Optics

ICFO-The Institute of Photonic Sciences

The field of photonics comprehends the generation, manipulation and detection of light (photons). Over the past decades, it has underpinned many of the technological advances upon which we rely on a daily basis, from our personal electronic devices and data communication channels (fibre optics), to medical instruments and lighting technologies. In line with this dependence, the photonics community is constantly seeking to develop novel technologies that can enable ever faster and powerful data communications, as well as compact and ultrasensitive monitoring systems. Advances made in this field depend greatly on the understanding and control we have over the light-matter interactions at play, with a strong focus on integrated photonic chip platforms due to their small footprint and scalability potential.

One of the main challenges to achieve fully integrated photonic chips deals with the emission coupling from nanoscale light sources to the on-chip photonic components. Ideally, the energy of a given light emitter should efficiently couple to sub-wavelength confined modes in order to fulfil scalability requirements. One solution is to implement metallic structures supporting surface plasmon polariton modes (i.e., coupled oscillations between photons and the free-electrons of the metal), which enable confinements beyond the diffraction limit of light.
This thesis deals with the development of hybrid photonic devices that enable the coupling of nanoscale light sources with on-chip plasmonic structures. These hybrid systems allowed us to influence the emission dynamics of the light sources, as well as transferring the emitted energy across the surface of a chip via subwavelength confined propagating modes. We implement state-of-the-art nanopositioning techniques to demonstrate various functioning hybrid devices operating with down to a single nanoscale emitter.

We start by exploiting a double high-resolution lithography approach combined with chemical functionalization, to assemble colloidal semiconductor quantum dots (QDs) at the hotspot of plasmonic nanoantennas. The antennas, designed to resonate with the excitation wavelength of our experiment, allow us to study the excitation enhancement provided by the metallic nanostructures by means of fluorescence lifetime measurements. We also provide some new insights about the limitations of the implemented positioning method.

Next, we turn our attention to explore the potential of the V-groove (VG) channel plasmon waveguides, to couple and transfer the emission from various nanoscale light sources across the surface of a chip. First, we explore the coupling of quantum emitters (i.e., particles able to emit single photons), with a focus on Nitrogen Vacancy (NV) centres in nanodiamonds and self-assembled QDs in semiconductor nanowires. In both cases, we relied on an atomic force microscope (AFM) based nanopositioning technique to bring the particles into the VG channels. We demonstrate for the first time the coupling of these type of quantum emitters to the channel plasmon polariton (CPP) modes supported by the VG waveguides, even down

to the single emitter-VG coupling scenarios.
Finally, we venture into developing plasmonic waveguide-integrated nanowire laser devices. To achieve this, the AFM nanopositioning technique allow assembling core-shell-cap semiconductor nanowires into wafer-scale compatible VG waveguides. Room temperature operation of this hybrid plasmon nanolaser is demonstrated, with a remarkable performance in terms of the transfer of energy from the hybrid plasmonic-photonic mode to the subwavelength confined propagating CPP mode of the VG.

The results presented in this thesis contribute to the list of potential hybrid photonic-plasmonic platforms applicable in future integrated photonic chip technologies. In particular, our devices based on the VG plasmonic waveguides, pave the way for the further development of more complex heterogeneous photonic circuitry.

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