STRONG LIGHT-MATTER INTERACTION IN 2D

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A leitmotif in nanophotonic research is the understanding and the intentional utilization of the interaction of single quantum emitters with their dielectric environment. The achievable enhancement and tunability of light-matter interaction promise new fundamental insight as well as potential applications, ranging from sensing to quantum computing.

In the last decade, the isolation of various two-dimensional (2D) materials has created a new paradigm in materials science and has already been proposed for a number of electronic applications in the area of ultra-thin and flexible devices. Graphene, a single atomic layer of carbon, can be considered the archetype 2D material whose extraordinary electronic, mechanical and optical properties have been proposed for practical applications, ranging from solar cells to optical modulators, and make graphene an ideal platform for strong light-matter interaction [1].

As for the emitters, organic molecules embedded in a solid state matrix are interesting alternatives to the more studied quantum dots or NVcenters in diamonds. A system made of Dibenzoterrylene (DBT) molecules embedded in thin Anthracene (Anth) crystalline films combines a bright and stable emission in the nearinfrared both at room and low temperature with easy fabrication techniques (spincoating or co-sublimation) [2]. As the produced DBT:Anth crystals are few tens of nm thick, they can be manipulated and integrated in diverse nanophotonic structures. At cryogenic temperature, the narrow emission around 785 nm which is not subject to dephasing i.e. it is lifetime-limited (< 40 MHz), makes DBT:Anth system particularly attractive for applications in quantum optics.

This project aim is to study different geometries and composition of a hybrid quantum system made of graphene coupled to this organic molecule-based single quantum emitter. Two main goal will be pursued: the development of a device for quantum position sensing and the achievement of strong coupling with graphene plasmons for quantum information protocols.

The interaction between graphene and the DBT:Anth system can be measured and verified experimentally with a confocal setup involving lifetime, excitation spectra and autocorrelation measurements, that allows to perform single molecule experiments Concerning the fabrication of the hybrid system, for the synthesis and characterization of the DBT:Anth crystals I can rely on the expertise on single molecules already established at LENS, where single molecule light sources are currently investigated both at room and at cryogenic temperatures. For the graphene sample I will refer to on-going collaborations with the Institute of Photonic Sciences (ICFO) in Barcelona and with the University of Exeter, where techniques for graphene fabrication and manipulation are well established.

In a first scheme, we plan to locate a suspended graphene sheet on top of a test chips with multiple arrays of holes of varying diameters (between 0.5 um to 5 um), depths (between 90 nm to 140 nm) and geometries filled with DBT:Anth crystals. At low temperature, this configuration would allow to study and accurately measure the Casimir forces between individual molecules and the graphene membrane. Their interaction is indeed predicted to yield a transition frequency shift of the single emitter which can be read out detecting the field scattered by individual molecule [3]. As the frequency shift strongly depends on the separation distance between single emitters and the graphene layer, this system would represent the first practical scheme for quantum sensing.

The second objective of my PhD project is to couple DBT:Anth crystals to intercalated graphene, i.e. a monolayer with increased concentration of charge carriers, to achieve the experimental condition ($E > 2E_F$, where E is the emitter transition energy and E_F is the Fermi energy of graphene) to excite graphene plasmons, that are expected to provide an attractive alternative to traditional noble metal plasmons [4].

References

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